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# EXPLORATORY DEVELOPMENT OF DESIGN DATA ON JOINTS USING FATIGUE-IMPROVEMENT FASTENERS

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AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
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This report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents fatigue design data on joints using fatigue-improvement fasteners. The major emphasis is placed upon low-load transfer specimens made of 7075-T73 and T7351 aluminum, assembled with PH13-8Mo and Ti-6Al-4V fasteners using the TaperLok, HiTigue, and split-sleeve mandrelized hole-fastening systems. The study revealed that the fatigue properties of fastener joints with mandrelized holes were similar to those of fastener joints with the TaperLok and HiTigue fastener systems. A method of condensed data presentation in MIL-HDBK-5 is proposed along with data requirements for future programs.

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## FOREWORD

The research reported herein was conducted by Battelle's Columbus Laboratories for the Materials Engineering Branch, Systems Support Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. The work was conducted under Contract No. F33615-73-C-5111, Project No. 7381, Task No. 738106. Alton W. Brisbane of AFML/MXE was the project engineer.

The study was conducted during the period June 1, 1973, to February 2, 1976. The program was conducted within the Structual Materials Section, Harold Mindlin, Manager. Stephen C. Ford was the principal investigator. The author wishes to express his appreciation to David A. Utah, researcher, and Lee R. Taggart, technician, Structural Materials Section for their assistance and meticulous attention to detail during the conduct of this program. This report was submitted by the author on May 28, 1976.

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## SUMMARY

This report presents the results of a program directed toward the development of design data on joints using fatigue-improvement fasteners. The program objectives were as follows:

- Develop statistically confident joint fatigue design data for three fastener systems (tapered-shank, TaperLok; straight-shank, HiTigue; straight-shank, mandrelized hole).
- Define those fastener or joint variables which affect the joint fatigue life using the three systems mentioned.
- Devise a concise presentation format compatible with MIL-HDBK-5 philosophy.
- Define data requirements (both type and quantity) for possible future inclusion in MIL-HDBK-5.

The results of this effort can be summarized as follows:

- The three fastener systems studied in this program provide similar low-load transfer joint fatigue properties when tested in well prepared interference holes. Although trends were apparent, similar conclusions could not be drawn for medium- and high-load transfer joints due to reduced data quantities.
- Positive or negative effects upon the nominal conditions above are observed when: (1) the interference level is changed, (2) the t/D ratio is reduced, and (3) the joint material or fastener head configuration is changed.
- A stress parameter, ($S_{max}\sqrt{1-R}$), can be used to obtain data collapse about the stress ratio, R.
- The above parameter makes it possible to present an S-N type curve and confidence bands to statistically depict a large quantity of data.
- Based upon the results of this program, candidate data requirements have been identified for future programs for proposed inclusion in MIL-HDBK-5

# 1. INTRODUCTION

The problem of fatigue of aircraft structures has been present since the first airplane was flown and has increased in magnitude with every advance in design technology. Today's level of design sophistication, coupled with ever increasing weight and cost concerns, has reclassified fatigue considerations from the problem to the design-parameter category.

Prior to the early 1960's, only token consideration was given to the fatigue life of fastened joints. However, the experience of recent years has made it apparent that a great majority of aircraft fatigue failures have occurred at, or passed through, fastener holes. As a result, more and more emphasis has been placed upon the development of fastened joint fatigue data for use in specific applications. To accomplish this, numerous simulated joint configurations and designs have been developed and evaluated for specific applications.

The increased emphasis on development of fastened joint fatigue data, coupled with a multitude of joint designs and materials, has brought about a vast quantity of fatigue data--most of which cannot be compared on a one-on-one basis. Recently, the Fastener Test Development Group of MIL-STD-1312 (Fasteners, Test Methods) prepared a proposed test, "Shear Joint Fatigue-Constant Amplitude", which defines specific joint configurations, materials, and test procedures. Implementation of these test requirements will provide the stepping-off point for the generation of a one-on-one comparable data base for the fatigue life of fastened joints.

For many years, MIL-HDBK-5[1] (containing fatigue design data for materials) has been considered the central depository of design data by aerospace engineers. In keeping with the intent of this document, it is the desire of the Air Force to include fatigue design data for fastened joints. If this goal is achieved, the aerospace design engineer will have, for the first time, comparable joint fatigue design data for several fastener system concepts. This will further facilitate fastener system selection, as sufficient information will be immediately available to make decisions based on comparative performance, cost, and producibility.

The research program reported herein was initiated by the Air Force to explore the ramifications and variables involved with the development of design data on joints using fatigue-improvement fasteners. Specifically, the objectives of the program were to (1) develop statistically comparable joint fatigue data for three fastener systems, (2) devise a MIL-HDBK-5 compatible presentation format, and (3) define data requirements (both type and quantity) for future inclusion in the Handbook. The approach was to develop baseline S-N type data for what were considered major variables and then test secondary variables against those baseline conditions to determine if there was any effect. Various data collapse parameters were considered along with data presentation formats.

Reported herein are the fastener and material selection process, joint specimen details, and the experimental matrix. The specimen preparation process is described, as well as methods of data presentation. The results of the experimental portion of the program, including data analysis are discussed. Recommendations are made for data presentation format and data requirements for future programs.

Appendix A contains the fatigue test results; the computer plotted curves resulting from the analyses are presented in Appendices B and C. Static joint test results and sheet material properties are documented in Appendices D and E, respectively. Appendix F contains the bending and load-transfer analysis of the high-load transfer joint configuration. Appendix G contains a listing of the computer programs used in the data analysis and plotting portion of the program.

## 2. PROGRAM OBJECTIVES

The major objective of the research program reported herein was the development of fatigue data for fastened joints utilizing fatigue-improvement-type fasteners. As the Air Force desired to include this type of data in Chapter 8 of MIL-HDBK-5, several secondary objectives were to be attained. First, a fatigue-data presentation format was to be devised which would provide airframe designers with a sound criterion for optimum fastener selection for fatigue-critical joints. Second, the presentation format had to be

compatible with the general philosophy of including only statistically confident data in MIL-HDBK-5. Finally, a standard data generation program had to be formulated to permit the inclusion of data for other fastener systems in MIL-HDBK-5 in the future. The fatigue data generation program had to take into account variables determined to be critical in this program as well as allowing enough flexibility so that future fastener designs could be evaluated fairly for comparison with current fastener designs.

## 3. FASTENER AND JOINT SELECTION

The experimental portion of the program was designed to accomplish a two-fold purpose: (1) develop an adequate quantity of joint fatigue data to provide a statistically confident presentation for inclusion in MIL-HDBK-5, and (2) investigate those fastener, fastener-installation, and joint variables which might be critical to the data presentation. The details and rationale concerning the selection of fastener systems and fastened joint specimens for use in the program are discussed in the following subsections.

### 3.1. Fastener Selection

Since this program was exploratory in nature, it was critical to select several fastener systems which were generally accepted and in use because of their fatigue-improvement qualities. In addition, it was desirable to investigate systems which had different fatigue-improvement mechanisms or installation processes. As a result, three fastener categories were selected for investigation; namely, the tapered-shank interference-fit, the straight-shank interference-fit, and straight-shank mandrelized-hole concepts.

#### 3.1.1. Tapered Shank, Interference Fit

The TaperLok system was a logical choice for this program as it is essentially the forerunner of the fatigue-improvement fasteners. It probably has the largest history of usage and fatigue data accumulation of any of the fatigue-improvement systems. This system relies upon the fatigue-improvement

mechanism of reducing alternating stress during cyclic loading, which has been well documented by Smith[2] and others.

The fastener is manufactured with a ¼-inch-per-foot taper on the shank which allows it to be pulled or pushed into a similarly tapered hole. The hole is drilled and reamed undersize to provide the desired level of interference between the pin and hole when the fastener is properly installed. The geometry of the system provides an easy determination of the interference level as a precision inspection pin or fastener will protrude 0.048 inch prior to installation for each 0.001 inch of interference after installation. This system requires careful control of the hole preparation process as the tapered reamer cuts along the full depth of the hole and chip accumulation or the wrong selection of feeds, speeds, and lubricants can cause fluted or out-of-round holes which in turn reduce the effective interference level and, hence, reduces fatigue life[3].

### 3.1.2. Straight Shank, Interference Fit

The second fastener system selected for investigation was the HiTigue, straight-shank interference-fit fastener. This system has gained a great deal of attention and primary usage in fatigue-critical aircraft structure. The system combines two fatigue-improvement principles in its operation--prestressing and interference fit. In addition to a slightly oversize shank (facilitating the insertion of the fastener into an interference-fit hole without causing or allowing the threaded area of the pin to come in contact with the hole which could cause scraping and galling), this fastener has a slight bead or ball section at the thread-to-shank juncture of the bolt. It is claimed that this bead accomplishes seven functions: (1) because the hole diameter is smaller than the shank diameter, it preloads the hole to provide beneficial residual compressive stress; (2) it cold works the hole; (3) it burnishes or polishes the hole much like the mandrelizing technique developed by Speakman[4]; (4) the installation process sizes the hole and essentially eliminates the problem of out-of-round holes and, hence, provides a constant degree of interference; (5) because the bead is larger than the shank diameter and leads the shank into the hole, the bead absorbs the majority of the frictional loading and, hence, protects the corrosion-resistant

and lubricant coatings deposited on the shank of the pin; (6) because the bead is small in size and essentially a sphere imposed on a cylindrical shank, its contact area with any portion of the hole is small, thus reducing installation loads and the likelihood of galling the hole during installation; and (7) the combination of cold working of the hole and leaving the hole in an interference-fit condition provides a fuel-tight sealed joint.

As with the tapered-shank fastener, the precision of the hole preparation process is a critical factor in controlling the final interference condition and, therefore, fatigue life. Although some cold working and burnishing of the hole is accomplished during fastener installation, it is believed that the interference fit (i.e. reduction of alternating stresses) is the major mechanism for fatigue-life improvement.

### 3.1.3. Straight Shank, Mandrelized Hole

The third fastener system involves the combination of a straight-shank fastener assembled in a cold-worked hole. In this case, one of the benefits considered by several aircraft companies is that no special proprietary fastener is necessary. The hole is sized, as described subsequently, to provide a slight interference to the fastener shank (also subsequently described). Of the five major methods of mandrelizing, the Boeing-developed "Sleeve Cold-Expansion"* process method has begun to receive considerable attention. In this procedure, a thin-wall split sleeve is inserted in the hole and a mandrel then is pulled through. This technique allows a great deal of latitude in hole-drilling tolerance and hole-finish conditions because the split sleeve is interfacing between the actual hole surface and the working mandrel. The use of the lubricated split sleeve allows the highest degree of radial cold expansion (0.010 to 0.050 inch, depending upon fastener diameter) attainable without concern for galling or overburnishing. The sleeve reduces the pulling load on the mandrel while absorbing the longitudinal frictional forces normally transferred to the hole interface. The high-level residual-compressive stress has been found to surround the hole to a distance

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* Sleeves and tooling were manufactured by Industrial Wire and Metal Forming, Inc., Tukwila, Washington.

in excess of one radius from the edge of the hole. Once the hole has been mandrelized, the sleeve is removed and the hole is reamed to the proper size to suit the selected fastener. The fastener is then installed in a line-to-line, very slight interference (0.002 inch maximum). The fatigue-improvement mechanism generated by this fastener system lies in the reduction of the maximum cyclic stress brought about by the residual compressive stresses imposed during the cold-working process.

### 3.1.4. Material Selection

Two parameters were considered when fastener material selections were made. First, it was considered important to consider two different strength levels of fasteners, and second, it was believed that elastic modulus of the fastener might well effect joint fatigue life. As a result, PH13-8Mo stainless steel and Ti-6Al-4V were selected because of the level of usage and their differing strength levels ($F_{su}$ = 125 ksi and 95 ksi, respectively) and elastic moduli (28.3 x $10^3$ ksi and 16.0 x $10^3$ ksi, respectively).

Nut and collar material selections were based upon fastener manufacturers' recommendations and compatibility with fastener and joint materials. With the exception of the PH13-8Mo HiTigue fastener, all nuts and collars were made of A-286 stainless steel. The exception was the HL1399 collar which was made of alloy steel with a type 302 stainless steel washer.

### 3.1.5. Fastener Configuration

Two fastener head styles were considered in this program. Major emphasis was placed on the shear-type countersunk head with secondary investigation of joints assembled with protruding shear head fasteners. Manufacturers' basic part designations are shown in Table 1. (The A-286 split sleeve, part number ST5300-CBS-0-N, was used with all straight-shank fasteners.)

### 3.1.6. Diameter and Grip

The major portion of the investigation was conducted using 3/8-inch-diameter fasteners; however, size effects were studied using 3/16- and

½-inch-diameter fasteners. Appropriate grip lengths were selected to allow assembly of specimens (using standard material gage thicknesses), with thickness-to-diameter ratios (t/D) of approximately 0.5 and 1.5.

TABLE 1. BASIC FASTENER DESIGNATIONS

| Fastener System | Material | Protruding Head | Flush Head | Nut |
|---|---|---|---|---|
| TaperLok | Ti-6Al-4V | TLV 200 | TLV 100 | TLN 1001 A-286 Washer Nut |
| TaperLok | PH13-8Mo | TLD 200 | TLD 100 | TLN 1001 A-286 Washer Nut |
| HiTigue | Ti-6Al-4V | HLT 10 | HLT 11 | HLT 97 A-286 Frangible |
| HiTigue | PH13-8Mo | HLT 34 | HLT 35 | HL 1399 Alloy Steel Frangible |
| Straight Shank | Ti-6Al-4V | HL 10 | HL 11 | HL 97 A-286 Frangible |
| Straight Shank | PH13-8Mo | HL 644 | HL 645 | HL 97 A-286 Frangible |

### 3.1.7. Finish and Lubrication

Fastener platings and lubricants were selected, as recommended by the fastener manufacturers, to be compatible with the joint materials being tested and to ensure proper fastener operation. The fastener finishes and lubricants for each of the fastener materials are shown in Table 2.

TABLE 2. FASTENER FINISH AND LUBRICATION

| Fastener | Pin Finish/Lubrication | Nut or Collar Finish/Lubrication |
|---|---|---|
| | PH13-8Mo Pins | |
| TaperLok | Passivate/Lubeco #2123 | Passivate/Cetyl Alcohol |
| HiTigue | Hi-Kote 2/Cetyl Alcohol | Nut-Cadmium Plate/Cetyl Alcohol Washer-Solid Film Lube per MIL-L-8937 |
| Straight Shank | Hi-Kote 2/Cetyl Alcohol | Lubeco #2123 |
| | 6Al-4V Pins | |
| TaperLok | Lubeco #2123 | Passivate/Cetyl Alcohol |
| HiTigue | Hi-Kote 2/Cetyl Alcohol | Silver Plate/Cetyl Alcohol |
| Straight Shank | Lubeco #2123 | Silver Plate/Cetyl Alcohol |

### 3.1.8. Installation Methods

All fastener installations were accomplished to the nominal interference or cold work values recommended by the manufacturer, except when installation effects were studied. In that case, fasteners were installed in minimum and maximum levels to generate data on the effects of hole drilling tolerance and interference or cold work levels on fatigue life.

The TaperLok fasteners were installed in accordance with Briles Installation Specification BPS No. 148; the HiTigue fasteners were installed in accordance with Hi-Shear Specification No. 299. These specifications define drills and drilling procedures, hole tolerances, and gaging. They also specify inspection methods, interference limits, and installation procedures.

Process Instructions IWMF-1-75 obtained from Industrial Wire and Metal Forming, Inc., and the work reported by the Boeing Company[(5)] were used to define the installation procedures for the mandrelizing process. Fastener interference and cold work levels are shown in Table 3 with installation torque levels shown in Table 4.

Some hold drilling and fastener installations were completed by Omark Industries and HiShear Corporation in order to assess laboratory-to-laboratory variations in the specimen preparation process. (Industrial Wire and Metal Forming, Inc., did not participate in this portion of the program.)

TABLE 3. FASTENER INTERFERENCE AND COLD WORK LEVELS

| Fastener | Diameter, inch | Level, inch | Range, inch |
|---|---|---|---|
| TaperLok[a] | 3/16 | 0.0025 | 0.0015 - 0.0036 |
| TaperLok[a] | 3/8 | 0.0040 | 0.0024 - 0.0054 |
| TaperLok[a] | 1/2 | 0.0048 | 0.0030 - 0.0066 |
| HiTigue[a] | All | 0.0045 | 0.0030 - 0.0060 |
| Mandrelize[b] | 3/16 | 0.0115 | 0.0105 - 0.0125 |
| | 3/8 | 0.0175 | 0.0160 - 0.0190 |
| | 1/2 | 0.0210 | 0.0195 - 0.0225 |
| Straight Shank[c] | All | 0.0020 | 0.0015 - 0.0025 |

[a] Interference-fit fastener.

[b] Cold work level using Boeing Split Sleeve/Mandrel system.

[c] Interference-fit fastener after cold work expansion of holes.

TABLE 4. INSTALLATION TORQUE[a]

| Diameter, inch | Grip | Bolt Material: PH13-8Mo TLN 1000 | PH13-8Mo HL 1399 | PH13-8Mo HL 97 | Ti-6Al-4V TLN 1000 | Ti-6Al-4V HLT and HL 97 |
|---|---|---|---|---|---|---|
| 3/16 | 0.500 | 45 ± 10 | 42 ± 7.5 | 30 ± 5 | 40 ± 10 | 30 ± 5 |
| 3/8 | 0.380 | 180 ± 15 | 235 ± 25 | 220 ± 20 | 170 ± 15 | 220 ± 20 |
| 3/8 | 1.250 | 320 ± 15 | 235 ± 25 | 220 ± 25 | 220 ± 20 | 220 ± 20 |
| 1/2 | 1.500 | 650 ± 30 | 450 ± 25 | 400 ± 30 | 625 ± 15 | 400 ± 30 |

[a] All torque values are in inch-lbs.

## 3.2. Fastened Joint Specimens

The selection of the joint configuration for evaluation of fastener fatigue life has historically been left to the discretion of the airframe designers. Usually, each interested party or organization would select or design a fatigue test specimen which they believed most closely matched their structural application. This led to a multiplicity of specimen configurations, which was in excess of 30 configurations in the simpler forms by the late 1960's. It was obvious that with the large number of specimens in use, there was no possibility of gathering any quantity of comparable data on any one type of fastener. Hence, the DoD-sponsored Fastener Test Development Group undertook a project to study and specify configurations and test conditions for joint lap-shear-fatigue testing. Combined military-industry consideration of the problem indicated that some comparative testing of these various joints would have to be conducted in order to determine which of the joints were sensitive to the influences of installed fasteners. Urzi[6,7] undertook projects under Navy and Air Force sponsorship to survey the industry, determine the types and configurations of joints in use, and evaluate those joints. He was able to separate the joint configurations into four basic types--no-load, low-load, medium-load, and high-load transfer. Comparative testing indicated that one configuration of each of the type of joints noted above was sensitive to the fatigue resistance of the fastener installed in it.

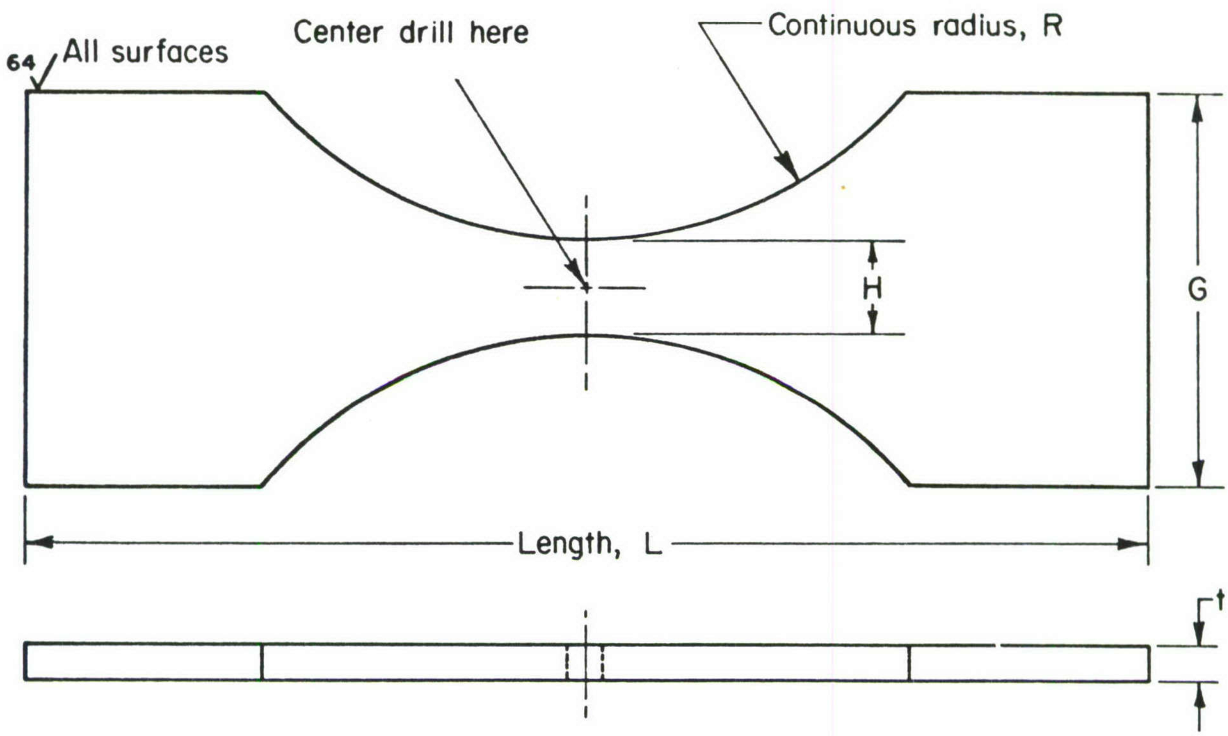
### 3.2.1. Configuration Selection

The specimen configurations used in this program are shown in Figures 1 through 4. These configurations, with the exception of Figure 3, are essentially those proposed by Urzi for inclusion in Test 21 of MIL-STD 1312. The specimen shown in Figure 1 was used to develop smooth specimen and open hole ($K_T \sim 3.1$) material fatigue data. The majority of the investigative effort revolved around the reverse dogbone (low-load-transfer) joint with some testing conducted on the simple-lap (100 percent load-transfer) joint and the modified 1½ dogbone (medium-load-transfer) joint. Sheet thicknesses were selected to provide a thickness-to-diameter ratio (t/D) ranging between approximately 0.5 and 1.5.

### 3.2.2. Joint Material Selection

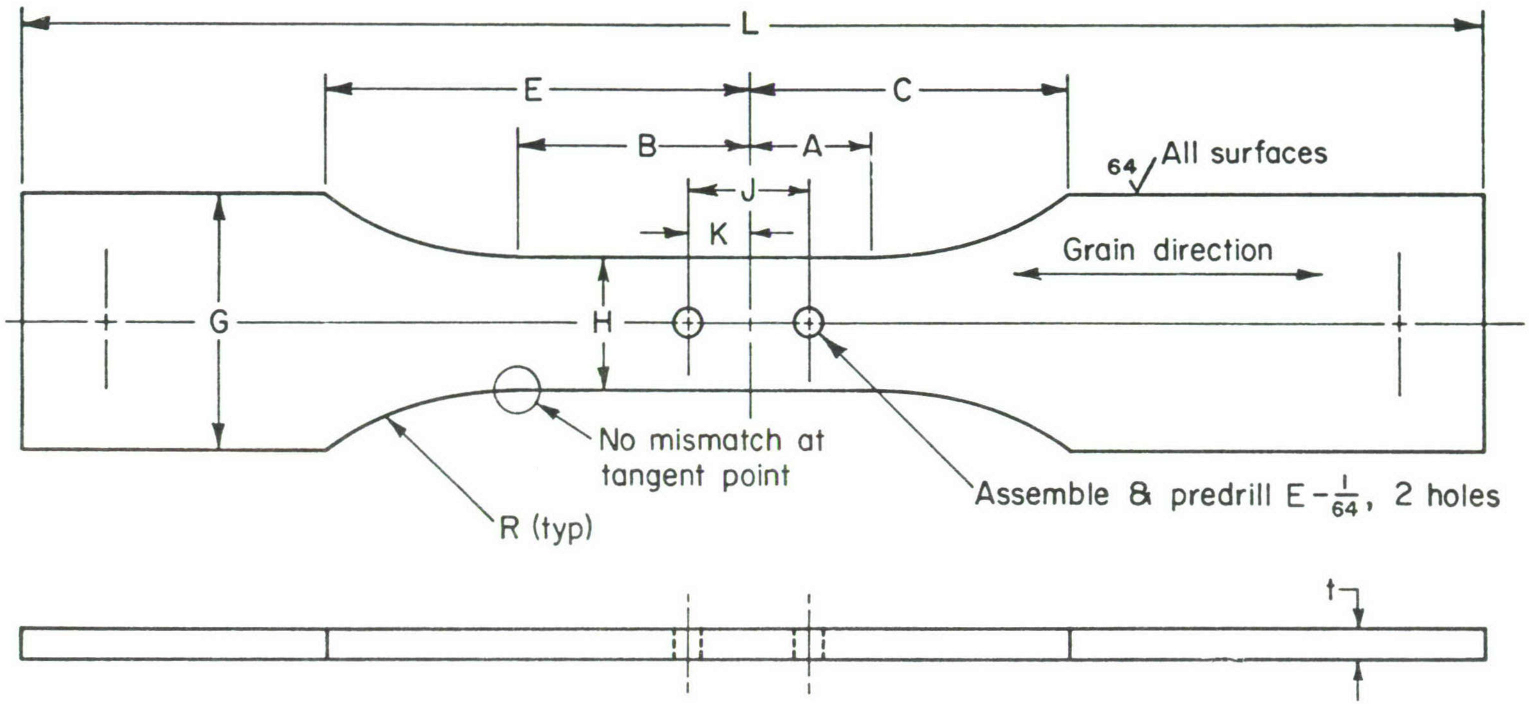
The selection of Ti-6Al-4V in the mill-annealed condition was fairly obvious based on the quantity used in industry. The next logical choice was an aluminum alloy; however, the selection of a particular alloy posed a problem. Aluminum 2024-T81 and -T851 are presently being given a fair amount of usage by industry; however, there is very little data published concerning fatigue properties. In addition, the 2000-series aluminum alloys are somewhat harder to machine and there was considerable concern that their "gummyness" might introduce extra hole drilling problems in the form of oval, out-of-round, and wormy holes.

As a result, the 7000-series alloys were considered and, after discussions with the project monitor, the 7075 alloy in the T73 and T7351 tempers was selected. These tempers have the lowest strength of the 7075 tempers, but have the highest toughness and lowest susceptibility to stress-corrosion cracking. In addition, they have very good machining properties, making consistent high quality hole preparation a possibility. Nonetheless, this material is more notch sensitive than 2024 and care must be exercised during specimen preparation to avoid nicks and gouges, especially on the fay surfaces, which can act as crack-initiation points.

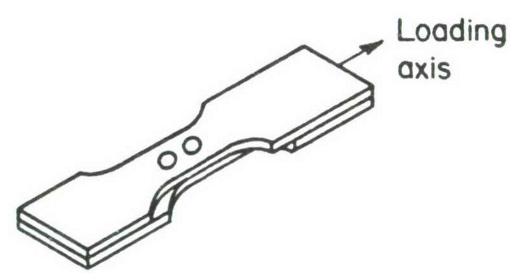



| NOMINAL D | ± .020 L | ± .010 G | ± .005 H | ± .020 R | THICKNESS t |
|---|---|---|---|---|---|
| 3/8 | 16.0 | 3.50 | 2.250 | 12.0 | .250 |
| 3/8 | 16.0 | 3.50 | 2.250 | 12.0 | .190, .625 |

FIGURE 1. SHEET STRENGTH (NO-LOAD) SPECIMEN

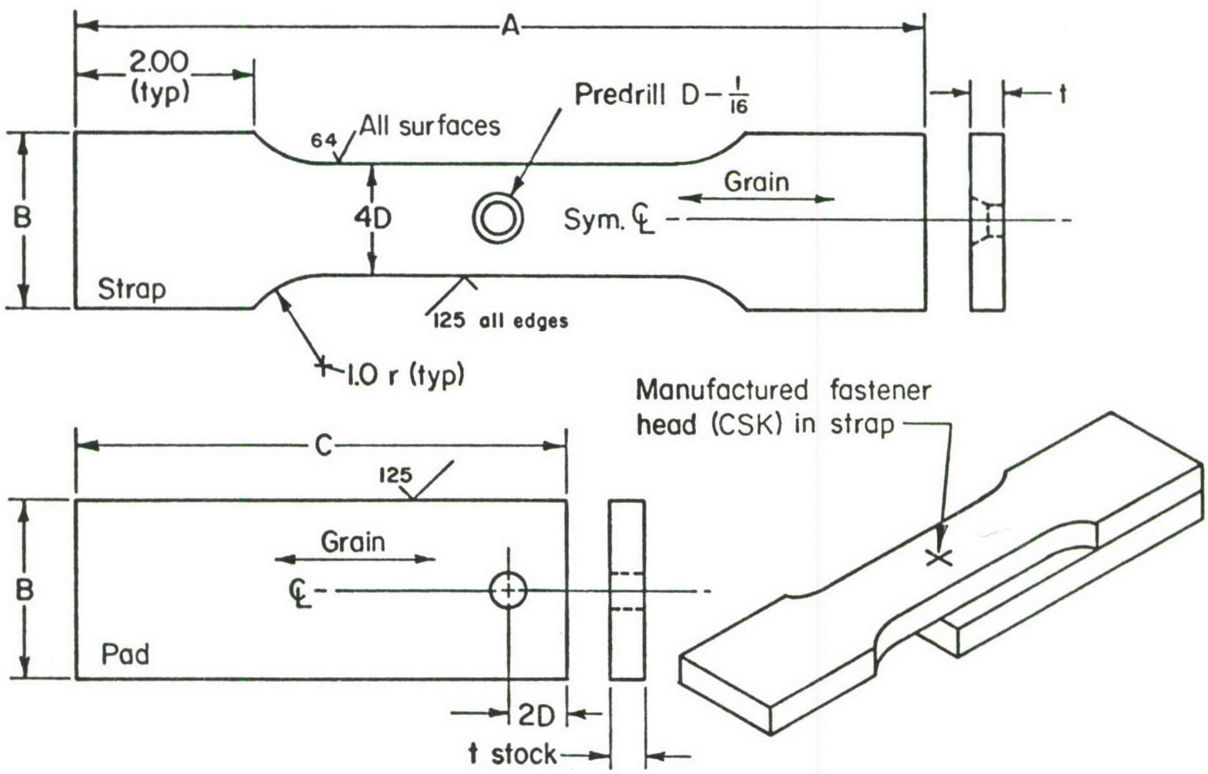



| NORMAL FASTENER SIZE | ± .010 L | ± .010 G | ± .005 H | ± .005 E | ± .005 C | ± .005 B | ± .005 A | ± .010 R | ± .005 J | ± .005 K | THICKNESS t |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/16 | 15.00 | 2.500 | 1.125 | 4.237 | 3.037 | 2.325 | 1.125 | 3.000 | .750 | .375 | .250 |
| 3/8 | 19.00 | 3.500 | 2.250 | 6.116 | 4.916 | 3.450 | 2.250 | 6.000 | 1.500 | .750 | .190<br>.625 |
| 1/2 | 21.00 | 5.000 | 3.000 | 8.070 | 6.870 | 4.200 | 3.000 | 8.000 | 2.000 | 1.000 | .750 |



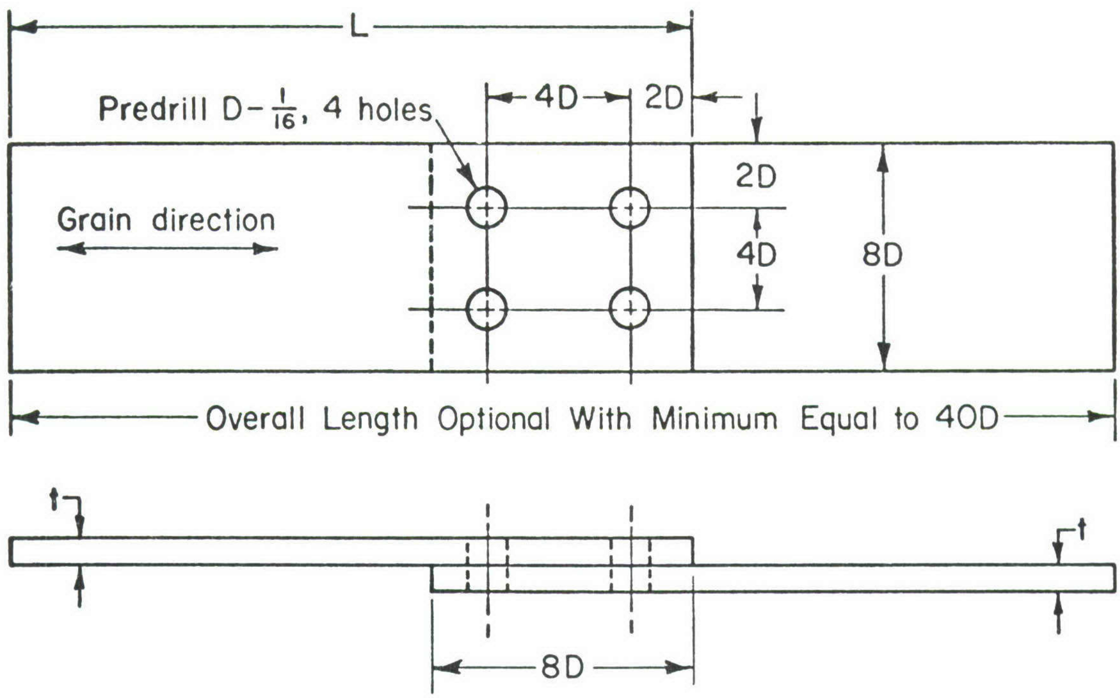

Assembly—reverse or offset dogbone specimen

FIGURE 2. LOW-LOAD-TRANSFER (REVERSE DOGBONE) TEST SPECIMEN




| NOMINAL D | ± .010 A | ± .010 B | ± .010 C | ± .005 2D | ± .005 4D | THICKNESS t |
|---|---|---|---|---|---|---|
| 3/8 | 11.00 | 2.25 | 6.25 | .750 | 1.500 | .625 |

FIGURE 3. MODIFIED MEDIUM-LOAD-TRANSFER (1½ DOGBONE) SPECIMEN




| NOMINAL D | ± .005 2D | ± .005 4D | ± .005 8D | ± .010 L | THICKNESS t |
|---|---|---|---|---|---|
| 3/16 | .375 | .750 | 1.500 | 5.500 | .250 |
| 3/8 | .750 | 1.500 | 3.000 | 11.000 | .190, .625 |
| 1/2 | 1.000 | 2.000 | 4.000 | 15.000 | .750 |

FIGURE 4. HIGH-LOAD-TRANSFER (SIMPLE-LAP-JOINT) SPECIMEN

## 4. EXPERIMENTAL PROGRAM

As stated earlier, the objective of the program was to explore the development of design data for joints using fatigue-improvement fasteners and to provide initial definition of test data requirements and presentation format. Because of the size of the task, it was necessary to design a test matrix which would provide as much usable data as possible without overlooking the effects of any important variables which might provide unconservative data when other fatigue-improvement fasteners were investigated. Several approaches were carefully considered in arriving at a test matrix that would achieve the objectives of this program. Because of the extensive number of specimens required for a completely factored, statistically designed experiment (involving 8 to 20 specimens for each variable), a modified statistical approach was taken. In the test matrix described subsequently, emphasis was placed on areas of prime concern--with limited examinations of secondary variables such that statistical analysis of the data would indicate the effects, positive or negative, of the variables relative to the fatigue behavior of a baseline condition. Prior to defining the actual test matrix, it was necessary to define some of the baseline conditions such as stress ratio; primary joint configuration, t/D ratio, and material; and primary bolt diameter, material, and head style.

### 4.1. Stress Ratio, R

Many of the presently available data have been generated at a stress ratio $\left(R = \frac{\text{minimum cyclic stress}}{\text{maximum cyclic stress}}\right)$ of 0.1. Although the exact reason for selecting this R value cannot be traced--even after considerable discussion with many airframe and fastener people--it may be that early fatigue machines operated best at R = 0.1.

From a practical application approach, it is not uncommon to see flight spectra loadings that include ground-air-ground cycles of R = - 0.4 or less, and gust loads of R = + 0.4 or greater. From these two considerations, R = + 0.25 and R = - 0.25 were selected for use in this program. Further justification of this selection can be made by examining the relationship of R values in the constant-life diagram.

At a given number of cycles to failure, each pair of R values will describe two points that can reasonably be connected by a straight line and, if sufficient data are available, some confidence bands. Comparison of Figure 5(a) and (b) shows that wider coverage and better interpolation and extrapolation can be obtained with the R = 0.25 and - 0.25 values with reasonable accuracy over the range of ± 0.45. In addition, if a parameter could be found to provide data collapse around the stress ratio, its effectiveness or accuracy could be better tested with the broader range of R = ± 0.25.

## 4.2. Primary Joint Configuration

The primary joint configuration was selected as the aluminum low-load transfer specimen. A primary t/D ratio of 1.5 was selected in an effort to find the greatest fastener system differences in thick stackups.

## 4.3. Primary Fastener Configuration

The 3/8-inch-diameter fastener was selected for baseline data generation as it is the middle of the extremes considered in this program. The flush-head configuration was used in order to produce the most conservative fatigue data; the PH13-8Mo material was selected because of the lower cost compared to titanium fasteners.

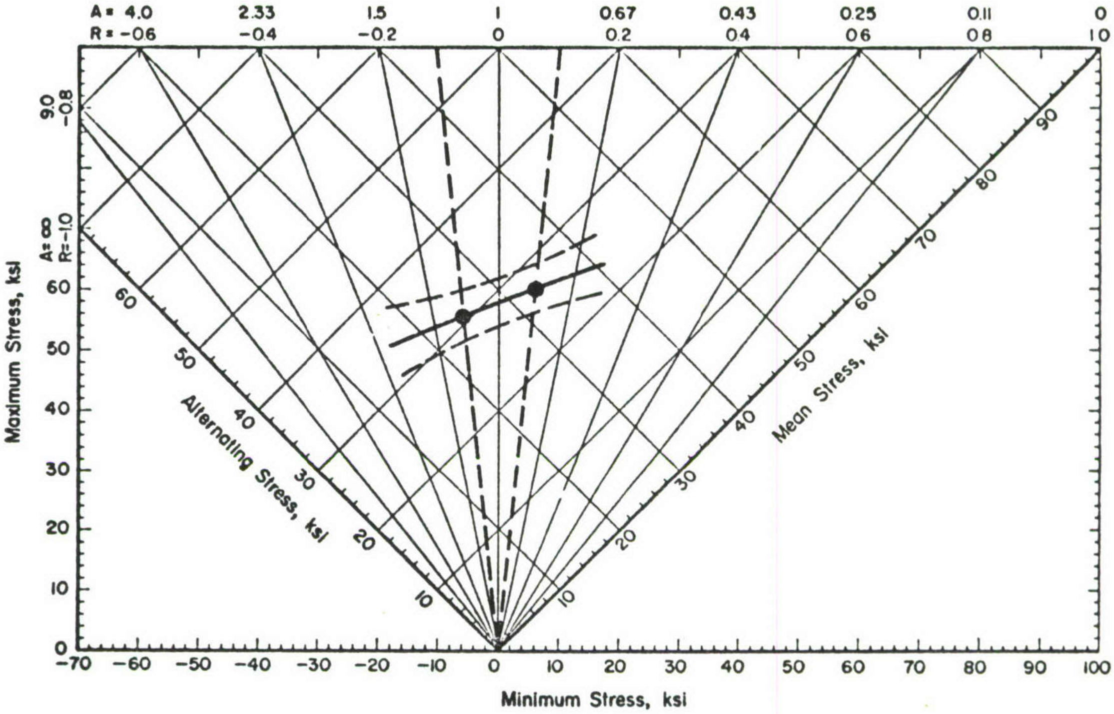
## 4.4. Summary of Variables

The primary variables detailed above are summarized as follows:

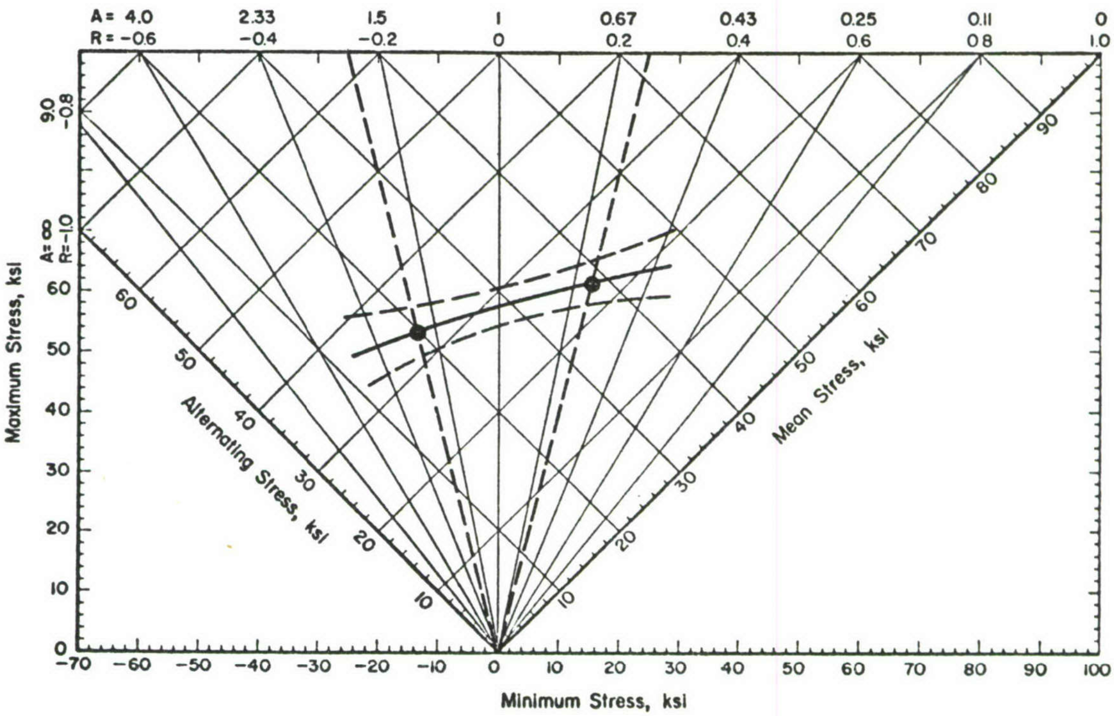
- 2 joint configurations
- 2 joint materials
- 1 bolt diameter
- 1 bolt material
- 1 bolt head style
- 1 t/D ratio
- 2 stress ratios.

The secondary variables (in the numbers indicated in parentheses) that were examined are as follows:

- Additional joint configuration (1)




(a) R = ± 0.1




(b) R = ± 0.25

FIGURE 5. CONSTANT LIFE DIAGRAMS

- Additional bolt diameters (2)
- Additional bolt material (1)
- Additional bolt head style (1)
- Additional t/D ratio (1)
- Additional stress ratios (2)
- Variations in installation condition (minimum and maximum).

## 4.5. Statistical Treatment of Data

As discussed earlier, statistical confidence in data intended for inclusion in MIL-HDBK-5 was one of the major objectives. This program was designed to provide the broadest possible coverage of the fastened-joint fatigue problem. The general approach was to define primary and secondary variables and give them separate statistical consideration. The primary variables were allotted more test specimens, thus making it possible to generate statistically confident fatigue curves. These curves were then used as baselines and secondary variables were tested to determine if a statistically measurable effect was present. Tests on the secondary variables were not intended to give an absolute measure of magnitude but only to establish if an effect is present. The general approach is discussed in the following paragraphs.

### 4.5.1. Fatigue Curves

After the important factors influencing fatigue life of a particular fastener/joint combination had been identified, a baseline set of data was generated for that combination. These data were used to define an S-N curve to which further comparison could be made. For each S-N curve, the stress levels and number of repetitions of these stress levels were selected to obtain maximum confidence on the mean curve while attempting to minimize the variance at all levels.

In fatigue testing, the optimum allocation of selected stress levels is highly dependent on the expected shape of the S-N curve, while the appropriate number of test repetitions at a given stress level is related to the

magnitude of variance in log fatigue life for the fatigue life interval of interest. In effect, this means, generally, that it may be useful to test some additional specimens in sections of the curve (at longer lives) where data variation is likely to be greatest.

After the test matrix for a given S-N curve had been defined and completed, an optimal regression curve was constructed. In the simplest case, fatigue life was considered only a function of some stress parameter and all other variables were held constant. This was based on an expression of the general form

$$\log_{10} N_f = A_1 + A_2 S + A_3 \log_{10} , \tag{1}$$

where $N_f$ = fatigue life in cycles (the dependent variable)

$S$ = a stress parameter (the independent variable) ($S_{max}$, Salt, etc.)

$A_1$, $A_2$, $A_3$ = regression coefficients.

BCL computer programs[8] facilitate the regression optimization of Equation (1). A quantitative estimate of goodness-of-fit was provided by way of the calculated statistical parameter, $r^2$, defined as the sum of squares of deviations of the dependent variable (in this case, $\log_{10} N_f$) from its mean associated with regression. Values of $r^2$ approaching 100 percent were most desirable, since that implied a large percentage of the variance of the dependent variable was attributable to the regression and that a good correlation between the dependent and independent variables had been established.

If fatigue life was truly a random variable, confidence limits could be established on the mean curve [Equation (1)] for any given stress level by use of the following expression:

$$\log_{10} N_f = \overline{\log_{10} N_f} \pm k(s.d.) , \tag{2}$$

where $\overline{\log_{10} N_f}$ = mean fatigue life calculated from Equation (1)

k = factor that depends on the sample size, n; the desired proportion of the population distribution; and the confidence at which this interval was estimated [9]

s.d. = logarithmic sample standard deviation (sample error of estimate of fatigue life values).

The calculation of confidence limits using Equation (2) required the assumption that the data were independent and log-normally distributed, with zero

mean deviations and constant variance[8]. Of these considerations, the uniformity of variance was of greatest concern as fatigue data generally tends to show increasing variance with increasing life. However, it was believed that the selection of a 90 percent confidence level and a 90 percent population distribution would provide a reasonable variance range at long lives and a conservative range at short lives. It was also believed that inspection of the $r^2$ statistic and standard deviation for each regression-optimized data set would provide adequate insight concerning log-normal distribution and zero mean deviations.

### 4.5.2. Secondary Variable Tests

After a baseline or mean curve with 90 percent confidence bands (see Figure 6) had been generated, a variable was then examined to determine if it had an effect on fatigue life, as discussed in the following paragraphs.

If the chances of the data falling to the left of the mean curve were 50-50, or $\frac{1}{2}$, then the probability of N test values falling to the left of the mean curve was $(\frac{1}{2})^N$. If five specimens were tested and they all fell to the left of the mean curve, then the probability of there being an effect (i.e., different from mean curve behavior) was $(\frac{1}{2})^5$ or 1/32. Ninety-five percent confidence is 5 chances in 100 or 5/100 or 1/20. If the data showed one chance in 32 of error and 95 percent confidence was one chance in 20, it can be said with greater than 95 percent confidence that the variable reduced fatigue life.

The same argument can be applied to a seven-specimen test lot. In this case, the probability of there being an effect is $(\frac{1}{2})^7$ (= 1/128) or one chance in 128. Ninety-nine percent confidence is one chance in 100 or 1/100. Hence, if all seven data points were to fall to the left of the mean curve, it could be said with 99 percent confidence that the variable reduced fatigue life. A similar argument can be made for four specimens and 90 percent confidence.

The converse argument (i.e., data to the right of the mean curve) can be used to show that a variable increased fatigue life.

A somewhat different argument can be applied for sample sizes of less than five or data falling outside of a confidence band. In this case,

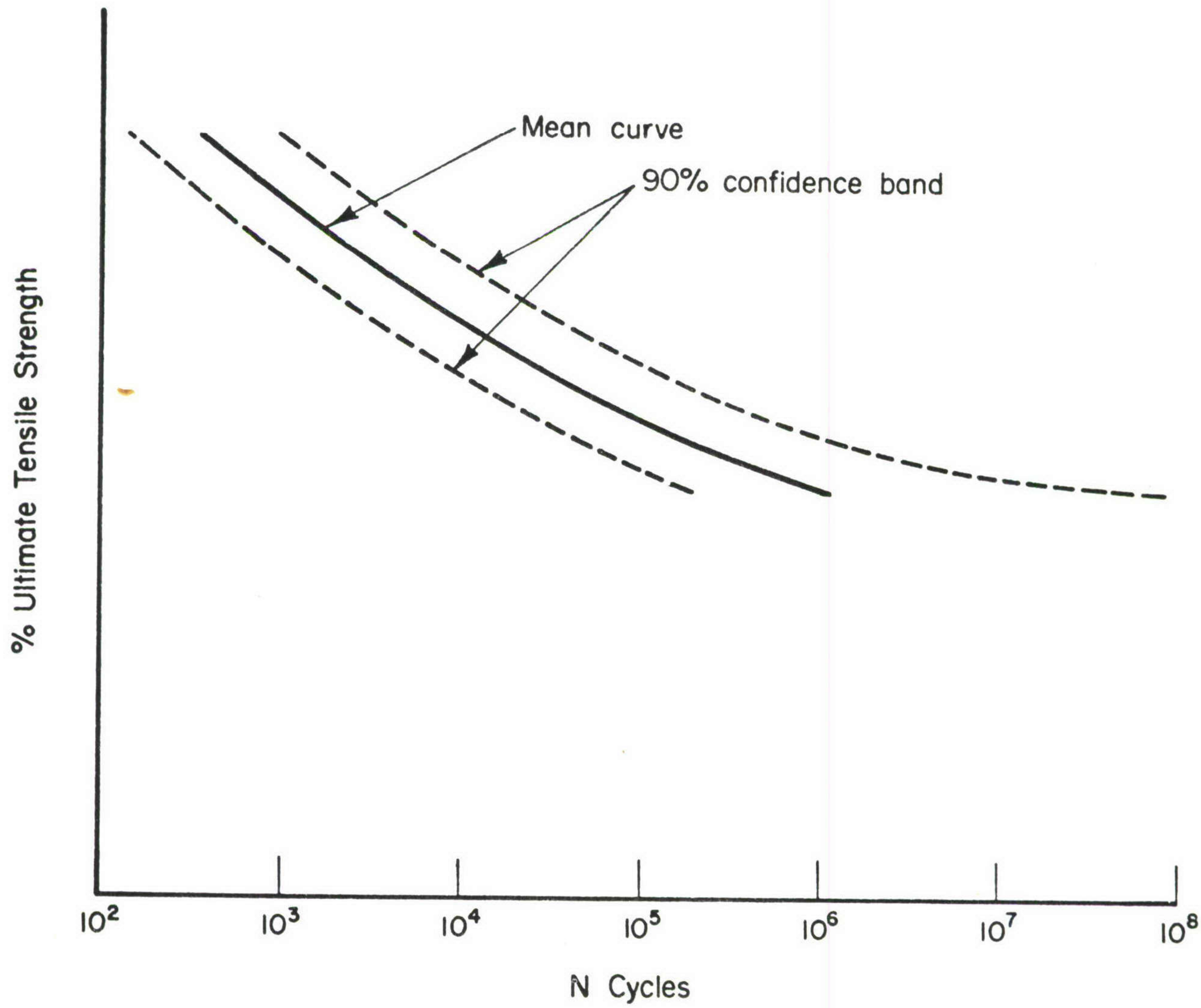



FIGURE 6. MEAN CURVE AND STATISTICAL CONFIDENCE BANDS

a well-defined baseline mean curve with a 90 percent confidence band is necessary. Here, we rely on the confidence band and say "we have 90 percent confidence that 90 percent of the data for this condition fall within the band". Thus, if we tested a small sample size (say four) and the data fell outside the band, we could be 90 percent confident that the data did not belong to the same family as that of the mean curve.

If the data from a secondary variable test should fall on both sides of the mean curve, one might conclude that the data could be combined with the mean curve data. In that case, the data can be tested statistically to determine if it belongs in the data family of the mean curve.

With this statistical basis, the test matrix described in the following paragraphs was determined.

## 4.6. Test Matrix

The first step in the program was confirmation of joint material properties as compared to existing data. Because data were available, a center point stress ratio of zero (R = 0) was used and R = ± 0.25 curves could be plotted from existing data with a correction factor added, if required. The specimens allocated for this portion of the program are shown in Table 5. Half of the specimens were smooth sheet and the other half had a center hole drilled to provide open-hole data (see Figure 1).

TABLE 5. SPECIMENS FOR DETERMINATION OF JOINT MATERIAL FATIGUE PROPERTIES[a]

| Test Series | Number of Specimens | Material | Thickness, inch | Nominal Diameter | Load | Notes |
|---|---|---|---|---|---|---|
| 54 | 2 | Al | .250 | 3/16" | ULT | Static |
| 54 | 10 | Al | .250 | 3/16" | S-N | |
| 55 | 2 | Al | .190 | 3/8" | ULT | Static |
| 55 | 10 | Al | .190 | 3/8" | S-N | |
| 56 | 2 | Al | .625 | 3/8" | ULT | Static |
| 56 | 10 | Al | .625 | 3/8" | S-N | |
| 57 | 2 | Ti | .250 | 3/8" | ULT | Static |
| 57 | 10 | Ti | .250 | 3/8" | S-N | |
| 58 | 2 | Ti | .625 | 3/8" | ULT | Static |
| 58 | 10 | Ti | .625 | 3/8" | S-N | |

[a] To be repeated with specimens with center hole drilled to nominal diameter shown above.

The second step was to conduct static and fatigue tests on the fastened joints shown in Table 6. This matrix was completed for each fastener type. Even though all fastener types were tested simultaneously to eliminate test machine and time-dependent errors, a description of the function of the matrix as conducted for any one fastener follows.

Test 1 provided ultimate tensile and yield strength data for that joint configuration. This test was conducted on all fastener and joint combinations included in this program.

Test 2 developed the fatigue curve for the same configuration with the load level related to ultimate tensile strength (UTS), if necessary. The fatigue curve was developed using a limited number of specimens; five or six specimens were tested at progressively lower load levels to determine the shape of the curve. Once the shape was established, loads of particular interest were selected and the individual tests replicated. After the test data were obtained, the statistical curve was determined for use as a baseline.

Test 3 examined the effect of minimum and maximum installation procedures. As discussed earlier, statistical tests conducted during the test sequence made it possible to conclude this test before all of the specimens were subjected to fatigue cycling. In some cases where the statistics indicated that an effect was present, it was desirable to continue the test so as to generate as much data as possible to evaluate the magnitude of the effect.

Test 4 was a repeat of Test 2 at the negative stress ratio. In this case, if Test 2 had defined the shape of the curve, fewer specimens were deemed necessary.

Test 5 considered a change in sheet thickness. These data were compared to the curve generated in Tests 2 and 4 to determine t/D effect.

Tests 6 and 7 considered different bolt diameters. The data were compared to the results of Tests 2 and 4.

Tests 8, 9, and 10 were identical to Tests 1, 2, and 3 with the exception that joint configuration was changed. A direct test for effect was made between the two series.

Tests 11 and 12 dealt with the change in bolt diameter and were treated in the same manner as Tests 6 and 7.

## TABLE 6. JOINT TEST PROGRAM FOR ONE FASTENER SYSTEM[a]

| Test Series | Number of Specimens | Joint Figure Number | Material | t/D | Bolt Diam | Bolt Material[b] | Load | R | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2 | Al | 1.5 | 3/8 | A | ULT | -- | Static |
| 2 | 15 | 2 | Al | 1.5 | 3/8 | A | S-N | +.25 | |
| 3 | 12 | 2 | Al | 1.5 | 3/8 | A | A-C | +.25 | Minimum and maximum installations, 6 each - 2 loads |
| 4 | 12 | 2 | Al | 1.5 | 3/8 | A | S-N | -.25 | |
| 5 | 4 | 2 | Al | .5 | 3/8 | A | A-B-C | ±.25 | 6 at each R - 2 at each load + 2 static |
| 6 | 8 | 2 | Al | 1.5 | 3/16 | A | A-C | +.25 | 3 at each of 2 loads + 2 static |
| 7 | 8 | 2 | Al | 1.5 | 1/2 | A | A-C | +.25 | 3 at each of 2 loads + 2 static |
| 8 | 2 | 4 | Al | 1.5 | 3/8 | A | ULT | -- | |
| 9 | 15 | 4 | Al | 1.5 | 3/8 | A | S-N | +.25 | |
| 10 | 12 | 4 | Al | 1.5 | 3/8 | A | S-N | -.25 | |
| 11 | 8 | 4 | Al | 1.5 | 3/16 | A | A-C | +.25 | 3 at each of 2 loads + 2 static |
| 12 | 8 | 4 | Al | 1.5 | 1/2 | A | A-C | +.25 | 3 at each of 2 loads + 2 static |
| 13 | 2 | 4 | Al | .5 | 3/8 | A | ULT | -- | Static |
| 14 | 12 | 4 | Al | .5 | 3/8 | A | A-C | ±.25 | 3 at each of 2 loads - both R's |
| 15 | 2 | 3 | Al | 1.5 | 3/8 | A | ULT | -- | Static |
| 16[c] | 6 | 3 | Al | 1.5 | 3/8 | A | A-B-C | +.25 | |
| 17[c] | 6 | 3 | Al | 1.5 | 3/8 | A | A-B-C | -.25 | |
| 18[d] | | | | | | | | | |
| 19[d] | | | | | | | | | |
| 20[d] | | | | | | | | | |
| 21 | 2 | 2 | Al | 1.5 | 3/8 | B | ULT | -- | Static |
| 22 | 12 | 2 | Al | 1.5 | 3/8 | B | S-N | +.25 | |
| 23 | 9 | 2 | Al | 1.5 | 3/8 | B | S-N | -.25 | |
| 24 | 2 | 2 | Al | .5 | 3/8 | B | ULT | -- | Static |
| 25 | 12 | 2 | Al | .5 | 3/8 | B | A-B-C | ±.25 | 2 each at 3 loads - both R's |
| 26 | 2 | 4 | Al | 1.5 | 3/8 | B | ULT | -- | Static |
| 27 | 12 | 4 | Al | 1.5 | 3/8 | B | A-B-C | ±.25 | 2 each at 3 loads - both R's |
| 28 | 2 | 4 | Al | .5 | 3/8 | B | ULT | -- | Static |
| 29 | 8 | 4 | Al | .5 | 3/8 | B | A-C | ±.25 | 2 each at 2 loads - both R's |
| 30 | 2 | 2 | Ti | 1.5 | 3/8 | A | ULT | -- | Static |
| 31 | 10 | 2 | Ti | 1.5 | 3/8 | A | S-N | +.25 | |
| 32 | 4 | 2 | Ti | 1.5 | 3/8 | A | A-C | -.25 | 2 each at 2 loads |
| 33 | 8 | 2 | Ti | 1.5 | 3/8 | A | A-C | +.25 | 2 each at 2 loads, minimum and maximum conditions |
| 34 | 2 | 2 | Ti | .5 | 3/8 | A | ULT | -- | Static |
| 35 | 6 | 2 | Ti | .5 | 3/8 | A | A-B-C | +.25 | 2 each at 3 loads |
| 36 | 2 | 4 | Ti | 1.5 | 3/8 | A | ULT | -- | Static |
| 37 | 6 | 4 | Ti | 1.5 | 3/8 | A | A-B-C | +.25 | 2 each at 3 loads |
| 38 | 2 | 4 | Ti | .5 | 3/8 | A | ULT | -- | Static |
| 39 | 6 | 4 | Ti | .5 | 3/8 | A | A-B-C | +.25 | 2 each at 3 loads |
| 40 | 2 | 2 | Ti | 1.5 | 3/8 | B | ULT | -- | Static |
| 41 | 8 | 2 | Ti | 1.5 | 3/8 | B | A-B-C | ±.25 | 2 each at 2 loads - both R's |
| 42 | 2 | 2 | Al | 1.5 | 3/8 | A[e] | ULT | -- | Static |
| 43 | 12 | 2 | Al | 1.5 | 3/8 | A[e] | A-B-C | ±.25 | 2 each at 3 loads - both R's |
| 44 | 2 | 2 | Al | .5 | 3/8 | A[e] | ULT | -- | Static |
| 45 | 12 | 2 | Al | .5 | 3/8 | A[e] | A-B-C | ±.25 | 2 each at 3 loads - both R's |
| 46 | 2 | 4 | Al | 1.5 | 3/8 | A[e] | ULT | -- | Static |
| 47 | 12 | 4 | Al | 1.5 | 3/8 | A[e] | A-B-C | ±.25 | 2 each at 3 loads - both R's |
| 48[f] | 4 | 2 | Al | 1.5 | 3/8 | A | A-C | +.1 | 2 each at 2 loads |
| 49[f] | 4 | 2 | Al | 1.5 | 3/8 | A | A-C | -1.0 | 2 each at 2 loads |
| 50[f] | 4 | 4 | Al | 1.5 | 3/8 | A | A-C | +.1 | 2 each at 2 loads |
| 51[f] | 4 | 4 | Al | 1.5 | 3/8 | A | A-C | -1.0 | 2 each at 2 loads |
| 52[f] | 4 | 2 | Ti | 1.5 | 3/8 | A[g] | A-C | +.1 | 2 each at 2 loads |
| 53[f] | 4 | 4 | Ti | 1.5 | 3/8 | A[g] | A-C | -1.0 | 2 each at 2 loads |

(a) To be repeated for all 3 fastening methods.
(b) Bolt material A is PH 13-8 Mo — Flush Head; bolt material B is 6Al-4V — Flush Head.
(c) Revised per agreement with technical monitor on June 7, 1973.
(d) Deleted per agreement with technical monitor on June 7, 1973.
(e) Bolt material A is PH 13-8 Mo — Protruding Head.
(f) Added per agreement with technical monitor on June 7, 1973.
(g) To be used for Boeing Mandrelized Hole concept only.

Tests 13 and 14 evaluated the effect of change of t/D ratio in the second joint configuration.

Tests 15, 16, and 17 evaluated the third joint configuration in much the same way as the first two configurations. The bolt diameter was held constant throughout.

Tests 21 through 29 evaluated the titanium bolt material in two joint configurations.

Tests 30 through 39 considered the PH13-8Mo bolt in two joint configurations fabricated from titanium material.

Tests 40 and 41 dealt with the titanium bolt in titanium material.

Tests 42 through 47 provided insights concerning the effect of protruding head bolts on joint life. The data were compared directly to the results of Tests 1 through 14.

Tests 48 through 53 provided additional comparative data at additional stress ratios in order to test further for any data collapse parameter.

It was possible (as discussed previously) to make statistically confident decisions concerning the effect of a variable relative to a baseline condition. Proper control of the test sequence allowed these tests to be made while the program was in progress. In some cases, it was possible to conclude that a particular variable definitely did or did not have an effect before all of the allotted specimens for that particular tests had been used.

## 4.7. Test Equipment and Environment

All fatigue experiments were conducted using one of four closed-loop electrohydraulic test systems, as appropriate. The systems are capable of applying maximum dynamic loads of ± 500,000, ± 130,000, ± 50,000, and ± 20,000 pounds, respectively. The systems were selected on the basis of load and compliance requirements of individual specimens to provide the most efficient system utilization. Cyclic loading frequencies varied from 3 to 25 Hz dependent upon specimen load and stroke requirements. All tests were conducted in an air-conditioned, humidity-controlled laboratory.

# 5. SPECIMEN PREPARATION

## 5.1. Specimen Blanks

Specimen blanks shown in Figures 1 through 4 were subcontracted to the Dyna-Quip Corporation, Columbus, Ohio. The aluminum material was ordered and delivered with adhesive-backed paper applied to both sheet surfaces. The protective paper was kept on the material during specimen blanking and hole drilling to minimize surface scratching and denting. As noted earlier, some of the blanks were sent to Omark Industries and the HiShear Corporation for hole drilling and fastener installation.

## 5.2. Fay Surface Treatment

Fay surface treatments were in accordance with proposed MIL-STD-1312 Test 21. High-load-transfer joints were degreased prior to assembly. Aluminum low-load and medium-load transfer specimens were degreased and coated with zinc chromate primer (per TT-P-1757) applied in accordance with MIL-P-6808. Titanium low-load-transfer specimens were coated with Molykote 106 and then cured for 60 minutes at 300 F. Study of AFML-TR-71-184 entitled "Fretting Resistant Coatings for Titanium Alloys" indicated that, other than degreasing, no preliminary surface treatment was required.

## 5.3. Hole Preparation

As noted earlier, all fastener holes were prepared in accordance with the manufacturers' recommended instructions. All holes were inspected to ensure that diameter, roundness, rifling, and tool marks were within acceptable limits. In addition, a statistical analysis was conducted on hole sizes to ensure proper interference levels. This was accomplished by computing a mean and standard deviation for each family of hole diameters. A range was then computed that encompassed 99.97 percent of the values (mean ± 3 standard deviations) and was compared to the minimum and maximum measured values.

### 5.3.1. Tapered Holes

Tapered holes were prepared using combination drill reamers obtained from Omark Industries. All holes were predrilled 1/64-inch undersize and then taper reamed. A master tapered pin with Prussian blue paint pigment applied was pressed into the hole with finger pressure and the protrusion was measured to determine the interference level as outlined earlier. The pin was then tapped into the hole approximately 25 percent of the protrusion value and removed. The pattern generated on the pin was checked visually to ensure a minimum of 80 percent bearing on all sheets. The protrusion value and percent bearing was recorded for each hole. A summary of computed interference values is presented in Table 7.

TABLE 7. TAPERLOK INTERFERENCE VALUES

| Nominal Diameter, inch | Mean Interference, inch | Standard Deviation, (s.d.), inch | Range, $\overline{X}$ ± 3 s.d., inch | Minimum/Maximum Measured, inch |
|---|---|---|---|---|
| 3/16 | 0.00253 | 0.00054 | 0.00199/0.00307 | 0.00204/0.00310 |
| 3/8 | 0.00418 | 0.00032 | 0.00321/0.00515 | 0.00311/0.00485 |
| 1/2 | 0.00556 | 0.000686 | 0.00350/0.00762 | 0.00531/0.00596 |

### 5.3.2 HiTigue Holes

Holes for HiTigue fasteners were prepared by predrilling 1/64-inch undersize and then reaming to the final diameter. All holes were checked visually to ensure good quality and all hole diameters were measured. A summary of hole sizes and computed interferences is presented in Tables 8 and 9.

TABLE 8. HITIGUE HOLE SIZES

| Nominal Diameter, inch | Mean Interference, inch | Standard Deviation, (s.d.), inch | Range, $\overline{X}$ ± 3 s.d., inch | Maximum/Minimum Measured, inch |
|---|---|---|---|---|
| 3/16 | 0.19074 | 0.000395 | 0.18955/0.19192 | 0.1901/0.1912 |
| 3/8 | 0.37517 | 0.000555 | 0.37462/0.37573 | 0.3747/0.3757 |
| 1/2 | 0.50054 | 0.000162 | 0.50006/0.50103 | 0/5002/0.5008 |

TABLE 9. HITIGUE INTERFERENCE VALUES

| Nominal Diameter, inch | Nominal Shank Diameter, inch | Mean Hole Diameter, inch | Mean Interference, inch |
|---|---|---|---|
| 3/16 | 0.1950 | 0.1907 | 0.0043 |
| 3/8 | 0.3800 | 0.3752 | 0.0048 |
| 1/2 | 0.5050 | 0.5005 | 0.0045 |

### 5.3.3. Mandrelized Holes

Holes for the mandrelizing process were drilled 1/64-inch undersize, reamed to final size, and measured. The holes were cold worked and then final reamed (approximately 0.007 inch material removed) to final size for fastener installation. A summary of cold working diameters and interference along with hole sizes and computed interferences is presented in Tables 10 through 13.

TABLE 10. MANDRELIZED COLD WORK LEVELS

| Nominal Diameter, inch | Nominal Hole Diameter, inch | Sleeve Wall Thickness, inch | Mandrel Diameter, inch | Cold Work Level, inch |
|---|---|---|---|---|
| 3/16 | 0.178 | 0.008 | 0.174 | 0.012 |
| 3/8 | 0.356 | 0.010 | 0.354 | 0.018 |
| 1/2 | 0.4725 | 0.012 | 0.4695 | 0.021 |

TABLE 11. MANDRELIZED HOLE SIZES BEFORE COLD WORKING

| Nominal Diameter, inch | Mean Diameter, inch | Standard Deviation, (s.d.), inch | Range, $\overline{X} \pm 3$ s.d., inch | Minimum/Maximum Measured, inch |
|---|---|---|---|---|
| 3/16 | 0.17822 | 0.00021 | 0.17759/0.17885 | 0.1776/0.1787 |
| 3/8 | 0.3557 | 0.00028 | 0.35486/0.35654 | 0.3550/0.3563 |
| 1/2 | 0.4724 | 0.00026 | 0.47162/0.47318 | 0.4715/0.4731 |

TABLE 12. MANDRELIZED HOLE SIZES AFTER COLD WORKING AND REAMING

| Nominal Diameter, inch | Mean Diameter, inch | Standard Deviation, (s.d.), inch | Range, $\overline{X} \pm 3$ s.d., inch | Minimum/Maximum Measured, inch |
|---|---|---|---|---|
| 3/16 | 0.1871 | 0.000224 | 0.18643/0.18777 | 0.1866/0.1877 |
| 3/8 | 0.372256 | 0.000177 | 0.37172/0.37279 | 0.3720/0.3727 |
| 1/2 | 0.49644 | 0.000167 | 0.4959/0.4969 | 0.4962/0.4967 |

TABLE 13. FINAL FASTENER INTERFERENCE LEVELS FOR MANDRELIZED HOLES

| Nominal Diameter, inch | Nominal Shank Diameter, inch | Mean Hole Diameter, inch | Mean Interference, inch |
|---|---|---|---|
| 3/16 | 0.1890 | 0.1871 | 0.0019 |
| 3/8 | 0.3740 | 0.3723 | 0.0017 |
| 1/2 | 0.4990 | 0.4964 | 0.0026 |

## 5.4. Specimen Supports

Antibuckling restraint similar to that shown in Figure 7 was provided for all specimens loaded at negative R ratios.

Initially, all high-load-transfer joints were provided with the sandwich-type bending restraint as defined in proposed Test 21 of MIL-STD-1312 and shown in Figure 7. However, study of the specimen while under load revealed extensive bending of the specimen outside of the restraint area was being transferred to the actuator of the test system. A secondary restraint system was devised which consisted of a pair of rollers contacting each of the restraint surfaces in an effort to reduce lateral motion of the restraint. In an effort to ensure that the secondary system did not impose any load transfer across the restraint, a specimen was strain gaged and load-strain data were obtained with the specimen restraint in place and with the specimen restraint and rollers in place. Analysis of that data indicated that load was being transferred across the restraint in both cases. Additional analysis led

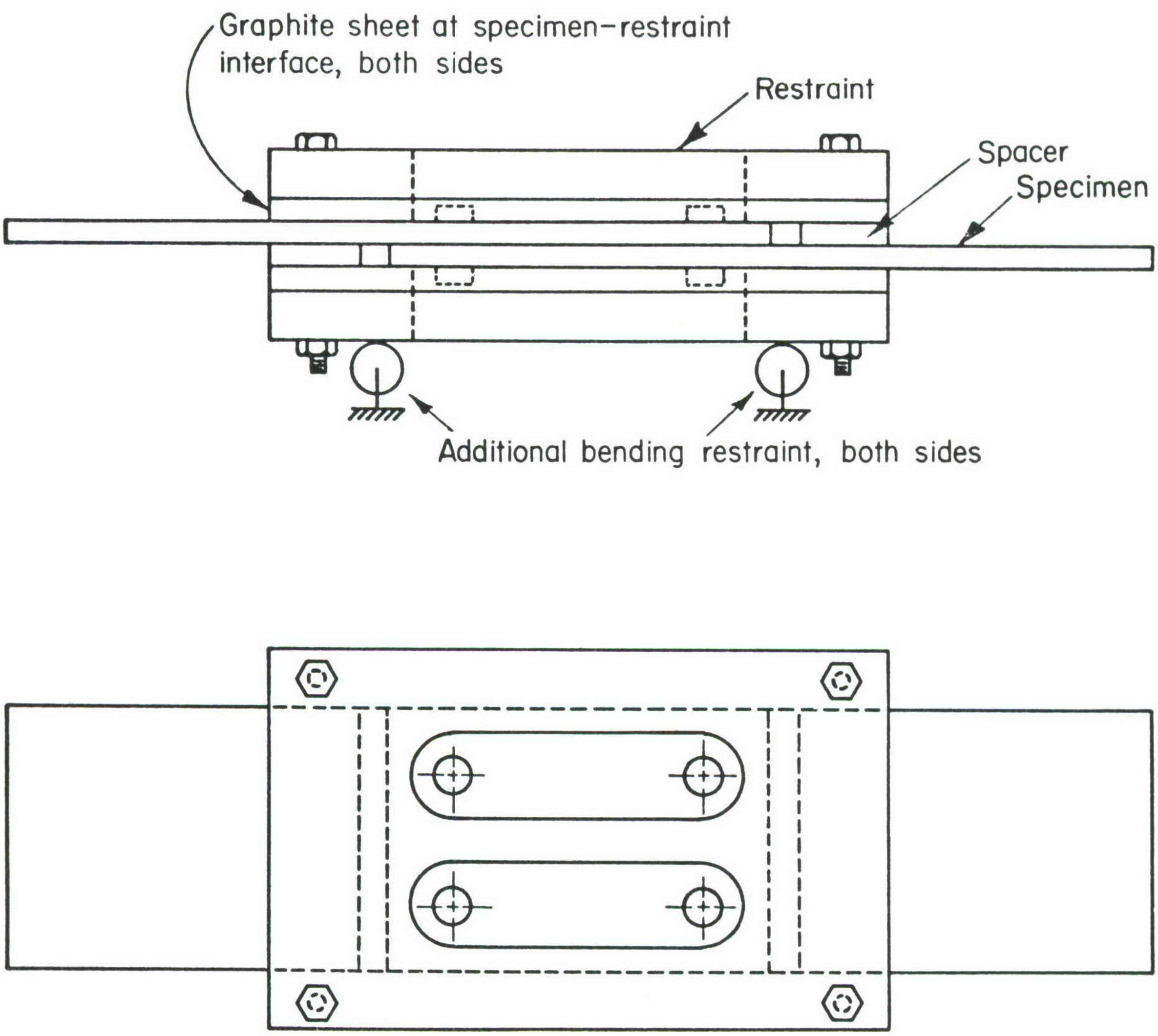



FIGURE 7. ANTIBUCKLING AND BENDING RESTRAINT

to the conclusion that thick joints ($t/D \geq 0.5$) could not be adequately restrained from bending without transferring some of the applied load across the restraint system. Hence, it is difficult to assess fastener effects when either the degree of joint bending is not known or the actual applied load in the joint area is unknown. (Details of the above-noted analysis are presented in Appendix F.) As a result, it was determined that the data being obtained for the high-load-transfer joint configuration were of little value in defining critical design data parameters and, hence, investigation of that joint configuration was stopped.

## 5.5. Specimen Identification

A specimen identification code was devised which made it possible to code the machined blanks and keep a data log of all operations on the specimen thereafter. The code is explained as follows:

| | Identification Code | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fastener | X | X | X | X | X | X | X | X | X |
| Straight-Shank Interference | S | | | | | | | | |
| Tapered-Shank Interference | T | | | | | | | | |
| Straight-Shank Mandrelized Hole | M | | | | | | | | |
| None | N | | | | | | | | |
| Bolt Material | | | | | | | | | |
| PH13-8Mo | | D | | | | | | | |
| Titanium | | V | | | | | | | |
| Bolt Head Type | | | | | | | | | |
| Flush Head | | | F | | | | | | |
| Protruding Head | | | P | | | | | | |
| Bolt Diameter (in 1/16's) None | | | | 0 | | | | | |
| 0.190 | | | | 3 | | | | | |
| 0.375 | | | | 6 | | | | | |
| 0.500 | | | | 8 | | | | | |
| Joint Configuration | | | | | | | | | |
| Sheet Strength | | | | | S | | | | |
| Low-Load Transfer | | | | | D | | | | |
| Modified 1½ Dogbone | | | | | L | | | | |
| High-Load Transfer | | | | | M | | | | |
| Joint Material | | | | | | | | | |
| Clad 7075-T73 Aluminum | | | | | | A | | | |
| 6Al-4V Titanium | | | | | | T | | | |
| Test Series | | | | | | | 1-9 | | |
| Specimen Number | | | | | | | | 1-99 | |
| Prepared by a Second Source | | | | | | | | | A |

For example, SDF6DT31-7 describes a specimen where a straight-shank interference, PH13-8Mo flush-head, 3/8-inch-diameter fastener is installed in a low-load-transfer joint made of Ti-6Al-4V. The specimen would be used for the seventh experiment of Test Series No. 31. An additional example might be NOSA59-4 which describes a nonfastened specimen in the no-load-transfer configuration made of aluminum, intended for the fourth experiment of Test Series No. 59.

## 6. METHODS OF DATA PRESENTATION

During the course of this program, constant consideration was given to the problem of data presentation format. Two major needs were identified: (1) a format which would facilitate data analysis and determination of critical variables and (2) a format which would be easily understood when included in MIL-HDBK-5. As it turned out, the solutions of the two problems went hand-in-hand.

### 6.1. Data Analysis Format

It was apparent from the onset of the data generation portion of the program that maximum data utilization could be accomplished only if some method could be found to negate or predict the effects of the stress ratio, R. If these effects could be negated or caused to collapse via the use of some parameter, then it was believed that data could be grouped to provide a broader and more statistically confident data base. Consideration of the fatigue improvement mechanisms of fastener systems indicated that maximum stress (for cold working) and alternating stresses (for interference-fit) should be included along with stress ratio if the parameter was to apply to the fastener systems used in this program. A combination of maximum and alternating stresses yielded the following parameter:

$$\begin{aligned}\sqrt{S_{max}\, S_{alt}} \text{ ksi} &= \sqrt{S_{max}\,(S_{max} - S_{min})} \\ &= S_{max}\sqrt{1 - \frac{S_{min}}{S_{max}}} \qquad (3) \\ &= S_{max}\sqrt{1 - R} \qquad \text{ksi} ,\end{aligned}$$

where $S_{max}$ = the stress having the highest algebraic value in the stress cycle

$S_{alt}$ = the alternating stress or stress range = $S_{max} - S_{min}$

$S_{min}$ = the stress having the lowest algebraic value in the cycle

R = the ratio of minimum stress to maximum stress.

This parameter is not new as Smith, et al[10], and Walker[11] developed forms for elastic and post-yield conditions and Rice, et al[8] demonstrated that both forms achieve a high degree of correlation. It should be kept in mind that the form (Eq. 3) discussed and used herein is primarily limited to elastic conditions. Plots of initial data using the $S_{max}\sqrt{1 - R}$ parameter provided very promising results and so attention was next given to curve fitting models.

### 6.2. Curve-Fitting Models

Several curve-fitting models were considered as it was believed that data analysis could most easily be completed using S-N type curves. The models considered included polynomial, tangent, power, and logarithmic functions. The polynomial and tangent functions showed some initial promise; however, each model required weighted curve-fitting constants at both short and long life for each data set, hence reducing the probability of combining data sets. Several power functions were fitted to sample data sets using the least-squares-regression technique and $r^2$ statistics ranging from 60 to 75 percent were obtained with generally poor fits occurring at short and medium lives. On the other hand, Equation (1) (the logarithmic function), when applied to the same data sets, provided $r^2$ statistics ranging from 95 to 98 percent. As a result, Equation (1) was selected for use in the regression optimization of data.

## 7. DISCUSSION OF FATIGUE RESULTS

As noted previously, Equation (1) was fitted to the fatigue test data (see Appendix A) using regression techniques. Each data set was analyzed to determine the equation of the mean curve, the sample estimate of the standard deviation, and the $r^2$ statistic. Fatigue-life data were plotted along with the mean curve and the 90 percent confidence limits.

## 7.1. S-N Curves

### 7.1.1. Aluminum Low-Load-Transfer Joints

Fatigue life curves for TaperLok fasteners in aluminum low-load-transfer joints, Test Series 2, 4, 22, and 23, are presented in Figures B-1 through B-4 of Appendix B. These curves are plotted using the $S_{max}\sqrt{1 - R}$ stress parameter versus $\log_{10}$ cycles to failure.

Fatigue life curves for the HiTigue fastener in aluminum low-load-transfer joints, Test Series 2, 4, 22, and 23, are presented in Figures B-5 through B-8 of Appendix B and similar curves for the mandrelized system are presented in Figures B-9 through B-12. Note that in all cases, the standard deviation is quite low and the $r^2$ value is always greater than 90 percent and generally greater than 95 percent.

Because of the apparent good curve fits obtained and similarities in curve equations, the analysis was expanded to investigate the combination of data sets. Test Series 2 and 4 and Series 22 and 23 were combined for the TaperLok, HiTigue, and mandrelized systems, respectively (Figures B-13 through B-18). Again, the low standard deviations and high $r^2$ values indicate very good curve fits and suggest that different stress ratios can be combined on the same curve using the $S_{max}\sqrt{1 - R}$ parameter. The latter hypothesis was further tested by combining data for Test Series 48 ($R = + 0.1$) and 49 ($R = - 1.0$) and Test Series 2 and 4 for the TaperLok, HiTigue, and mandrelized systems, respectively. Again, good fitting was obtained (Figures B-19 through B-21).

Data were combined for steel fasteners (Series 2 and 4) with data for titanium fasteners (Series 22 and 23) with extremely good results (Figures B-22 through B-24).

At this point, it was apparent that the parameter $S_{max}\sqrt{1 - R}$ and the curve fitting equation were working quite well and further data pooling was considered. Data pooled for Test Series 2 and 4 for all three fastener systems produced a very good curve fit (Figure B-25). One data point that fell outside of the 90 percent band at a high stress level where the assumption of joint material elasticity may not be valid; nonetheless, 68 of the 69 data points (98.5 percent) were contained within the 90 percent band.

The data pooling process was continued (Figure B-26) wherein Test Series 48 and 49 data were added to that for Test Series 2 and 4 for all three fastener systems. Again, the standard deviation was small and the $r^2$ value high. The additional data caused a minor shift of the mean curve and the tolerance band; however, 89 of the 93, or 95.7 percent of the data points, were contained within the 90 percent band.

Data for Test Series 2, 4, 48, 49, 22, and 23 for all three fastener systems were then combined to produce one curve, Figure B-27. The changes in the curve, when compared to the preceding two figures, were minor with very small changes in standard deviation and $r^2$ values. Only eight of the data points fell outside of the 90 percent band, leaving 143 points or 94.7 percent of the data within the band.

It is believed that Figure B-27 is a reasonable example of normal fatigue data scatter and indicates that the data for the three fastener systems can be considered as one data population. Hence, the mean line and 90 percent band from Figure B-27 were used as a basis to evaluate the individual fastener variables in the low-load-transfer joint configuration.

#### 7.1.2. Aluminum High-Load-Transfer Joints

Data generated for the aluminum high-load-transfer joint configuration at stress ratios of + 0.25 and - 0.25 are shown for the TaperLok and HiTigue fastener systems in Figures B-28 through B-31. Good curve fitting is seen in the standard deviation and $r^2$ values. The combining of stress ratios for each fastener system produced good fitting parameters (Figures B-32 and B-33).

Study of the last two curves (Figures B-32 and B-33) revealed greater difference than had previously had been observed for similar test series combinations. Study of joint failure modes also indicated a definite trend to develop gross section failures near the edge of the joint lap at low loads and fay surface failures at the hole at high loads. It appeared that the change in failure mode was due to the ineffectiveness of the bending restraints with such thick joints. To investigate this further, a specimen was instrumented with strain gages and load-strain data obtained and analyzed. The data indicated that bending was occurring. Attempts to eliminate bending

resulted in load transfer across the restraint and as a result, it was decided to forego any further testing on this specimen configuration. It was obvious that the mixed failure modes did not reflect fastener effects in the joint but, instead, reflected effects of the restraint system on the joint. (A further discussion of these findings is presented in Appendix F.)

### 7.1.3. Aluminum Medium-Load-Transfer Joints

No data were generated for the medium-load-transfer joint due to problems similar to those described for the high-load-transfer joint configuration. In this case, the joint members were also thick enough to generate substantial bending stresses. Efforts to reduce the bending via restraint systems proved unsuccessful since load was once again transferred across the restraint making determination of load applied to the specimen impractical.

### 7.1.4. Titanium Low-Load-Transfer Joints

The results of Test Series 31 for a steel TaperLok in a titanium low-load-transfer joint indicated a higher degree of scatter than is generally obtained for aluminum joints, as noted by the standard deviation and $r^2$ values (Figure B-34).

A similar curve for the HiTigue fastener system is not available as fasteners one grip length shorter than necessary were mistakenly installed in the specimens. The error was not detected until testing had started. All failures were occurring at the outer joint surface on the nut side of the joint where there was no fastener interference.

Although the curve fit for the mandrelized system was very good, the shape of the curve at high stresses is somewhat unusual and unexplained (Figure B-35).

The addition of test data from Test Series 52 ($R = +0.1$) to the data from Test 31 ($R = +0.25$) for the mandrelized system had little effect upon the curve equation and indicated that the stress parameter was adequate for titanium joints as well as aluminum joints (Figure B-36).

## 7.2. Consideration of Variables

In order to maintain continuity, the secondary variables discussed earlier will be examined for each fastener system separately with general comparisons between systems presented in a later section.

### 7.2.1. TaperLok Secondary Variables

The maximum interference condition provided decidedly higher life and, in fact, had one value outside of the 90 percent population band. The effect of minimum and maximum interference levels upon fatigue life is illustrated in Figure C-1.

A reduction in t/D ratio produced higher fatigue life for this fastener system, especially at positive stress ratios (Figure C-2). Again, data fell outside of the 90 percent population band.

A reduction in fastener size may have possibly provided a slight increase in fatigue life--but not enough to exceed the 90 percent population band (Figure C-3).

The effects of protruding-head fasteners compared to flush-head fasteners were very small, if not nonexistent, at high t/D ratios (Figure C-4).

The effect of a titanium fastener and a reduced t/D combination produced a slight increase in life for specimens tested at positive stress ratios; however, the trend did not exceed the 90 percent population limits (Figure C-5).

There appears to be a slight tendency toward increased fatigue life for protruding head fasteners in thinner stackups (Figure C-6).

### 7.2.2. HiTigue Secondary Variables

The HiTigue fastener system was apparently somewhat more sensitive to installation conditions than the TaperLok. In this case, the maximum interference-level data remained scattered around the mean line, but the minimum level data all fell below the line with one value outside the 90 percent population limit (Figure C-7).

The joint fatigue life for this fastener system definitely improved in thinner joints with 5 of the 11 (45 percent) data points falling outside of the 90 percent population limit (Figure C-8).

Interpretation of fastener size effects was somewhat clouded by the behavior of the 3/16-inch-diameter data. It appeared that two failure modes controlled the joint behavior. At low stress, fatigue life of the smaller fastener joint was definitely increased with failures occurring at the fastener head or fay surface. At high stress, fatigue life was somewhat reduced with failures occurring along the fastener shank. Increasing the fastener size to ½-inch diameter appeared to have no effect (Figure C-9).

Data for the HiTigue system confirmed an increase in life with thinner joints and again primarily at positive stress ratios (Figure C-10).

Positive stress ratio data for the protruding-head fastener in thick joints ($t/D \sim 1.5$) fell on both sides of the mean line with a trend for reduced life with reduced stress when compared to the mean line. However, all positive stress ratio data fell within the 90 percent population band. This same trend is applicable to the negative stress ratio; however, one point fell outside the 90 percent population band indicating a definite positive effect (Figure C-11).

A study of the effects of protruding-head fasteners in thin joints ($t/D \sim 0.5$) showed that the data for both stress ratios fell outside the 90 percent population limit indicating that protruding-head fasteners in thin sheets did, indeed, provide life increases over the baseline thick sheet, flush-head conditions (Figure C-12).

### 7.2.3. Mandrelized System Secondary Variables

The findings of the previously mentioned Boeing study, in that fatigue life was definitely reduced with lower levels of cold work, was supported by the data shown in Figure C-13. Unfortunately, maximum levels of cold work could not be obtained as the mandrel pulling shank was too large to fit into the reduced hole size required for maximum cold-work levels.

As with the other systems, fatigue life increases were indicated due to reduced sheet thickness. In this instance, stress ratio effects were

not as prevalent as was the case with the other two fastener systems (Figure C-14). The test data indicated an increase in fatigue life for reduced fastener sizes (Figure C-15).

A high degree of scatter in the fatigue data was indicated when titanium fasteners were installed in thin joints as the positive stress ratio data fell outside of both sides of the 90 percent population band. The negative stress ratio data did show an effect for increased life, especially at higher stress levels. Hence, one would conjecture that the overall effect of reduced sheet thickness and titanium fasteners was one of increased life (Figure C-16), as with the other two systems.

The effects of protruding-head fasteners in thick sheets were shown to be negligible (Figure C-17), as was the case with the other two fastener systems.

Again, as shown for the other two fastener systems, a reduction of sheet thickness and use of protruding-head fasteners provided a definite increase in fatigue life (Figure C-18).

### 7.2.4. Titanium Joint Secondary Variables

The effect of interference level on titanium joints is shown for the TaperLok in Figure C-19. It appears that maximum interference reduced life at lower stresses while minimum interference showed very little effect.

The effect of reduced titanium joint thickness appears to be negligible and the data for the reduced t/D ratio belongs in the same family as Test Series 31 (Figure C-20).

Figures C-21 and C-22 present data for Test Series 33 and 35, respectively, for the HiTigue as compared to the TaperLok baseline curve (Test Series 31). It is apparent that had the Test Series 31 curve for the HiTigue fastener been generated, it would have been substantially different from the TaperLok curve. This is evidenced by the fact that equivalent Figures C-19 and C-20 for the TaperLok system show data falling generally within the 90 percent population band.

The effect of the reduced titanium joint thickness of Test Series 35 for the mandrelized system was compared to the combined baseline of Series 31 and 52. There was a definite trend in the direction of reduced life at

lower operating stress levels (Figure C-23). This trend was similar to, but more extreme than, that observed for the same TaperLok test series (Figure C-20).

### 7.3. Summary of Fatigue Results

As discussed earlier, the fact that S-N data for all three fastener systems could be combined on one S-N curve indicated that there was very little difference in the fatigue life behavior of the systems for the baseline condition. It is very unlikely that these results would have been possible if careful attention had not been paid to test specimen preparation. Once again, the baseline condition was defined as a 3/8-inch diameter (D) flush-head fastener installed at the nominal (mean) interference level in an aluminum or titanium low-load-transfer specimen, with single sheet thickness (t) such that the t/D ratio was approximately 1.5. Fatigue testing was conducted at stress ratios of $\pm$ 0.25, + 0.1, and - 1.0.

Analysis of the results of secondary variable tests (presented in Appendix C) revealed the following:

- Minimum and maximum installation conditions had a definite effect upon fatigue life for all three fastener systems.
- Reduced joint sheet thicknesses resulted in an increase of fatigue life of aluminum joint specimens (possibly due to better hole preparation in this sheet) and yielded a slight reduction in life for those titanium joints tested at lower stress levels (possibly due to the increased data scatter in titanium joint material).
- Joints assembled with protruding-head fasteners when compared to these assembled with flush head fasteners, showed very slight increases in fatigue life in thick joints where the percent increase in net section area is small and a fairly substantial increase in fatigue life when testing was conducted on thinner joints, where the relative increase in net section area is larger.

## 8. STATIC-JOINT TESTS

Static-joint tests were conducted using universal testing machines and an LVDT-type extensometer. Yield loads were determined from the autographic load-deflection record by the 0.2-percent-offset method when the failure mode and ultimate load indicated sheet material tensile failure or by the 0.04D (where D is the nominal fastener diameter) offset method when the fastener failed. The tables in Appendix D report critical dimensions, yield and ultimate loads, and gross section stresses.

The magnitude of net section stresses indicated that full material strength was developed for low-load-transfer joints. This is indeed fortunate in that the initial test of a titanium low-load-transfer joint resulted in severe damage to the gripping jaws and jaw adjustment mechanism, hence making further testing impossible. However, titanium material certification data make it possible to compute either net or gross section yield and ultimate loads with a high degree of confidence.

Analysis of the high-load-transfer static-joint data indicated the need to develop such data for any joints included in future programs as net and gross section stress did not compare well with material strength data. This was to be expected as this joint was subjected to severe bending--static-joint failures generally consist of a combination of fastener and joint material failure modes.

## 9. SHEET MATERIAL PROPERTIES

Sheet material fatigue data and S-N curves are reported in Appendix E along with material certifications. The data are somewhat lower than that supplied by Alcoa[12]; however, the Alcoa data were for smooth-machined tensile bars and one would expect to observe some reduction in fatigue life when testing mill-quality plate specimens.

## 10. RECOMMENDED PRESENTATION FORMAT

The primary concern when considering possible joint fatigue data presentation formats is that of providing the design engineer data in the most understandable manner. It was shown earlier that the stress parameter,

$S_{max}\sqrt{1 - R}$, provides excellent data consolidation for the life range of 3,000 to 10 million cycles. In addition, the use of this parameter makes it possible to obtain fatigue life information for any number of stress ratios from one S-N type curve. The use of the 90 percent confidence--90 percent population bands on the S-N curve provide an immediate assessment of data scatter.

It is recommended that the proposed MIL-HDBK-5 presentation format, shown in Figure 8, be utilized. It provides for future addition of equivalent fastener systems as well as an assessment of the effects of variables which may be confirmed, if necessary, for specific applications. If this approach is unacceptable, the necessary data may be extracted from the curve in Figure 8 and a modified constant life diagram can be constructed as shown in Figure 9. This format is more familiar to the design engineer, but does not contain any indications of data scatter.

## 11. RECOMMENDED DATA GENERATION PROGRAM

Based upon the findings of this program, it is recommended that fastener systems proposed for future inclusion in the joint fatigue-life section of MIL-HDBK-5 be subjected to an experimental program to include the following tests:

(1) One S-N curve consisting of a minimum of 12 specimens at each of two stress ratios (24 specimens)

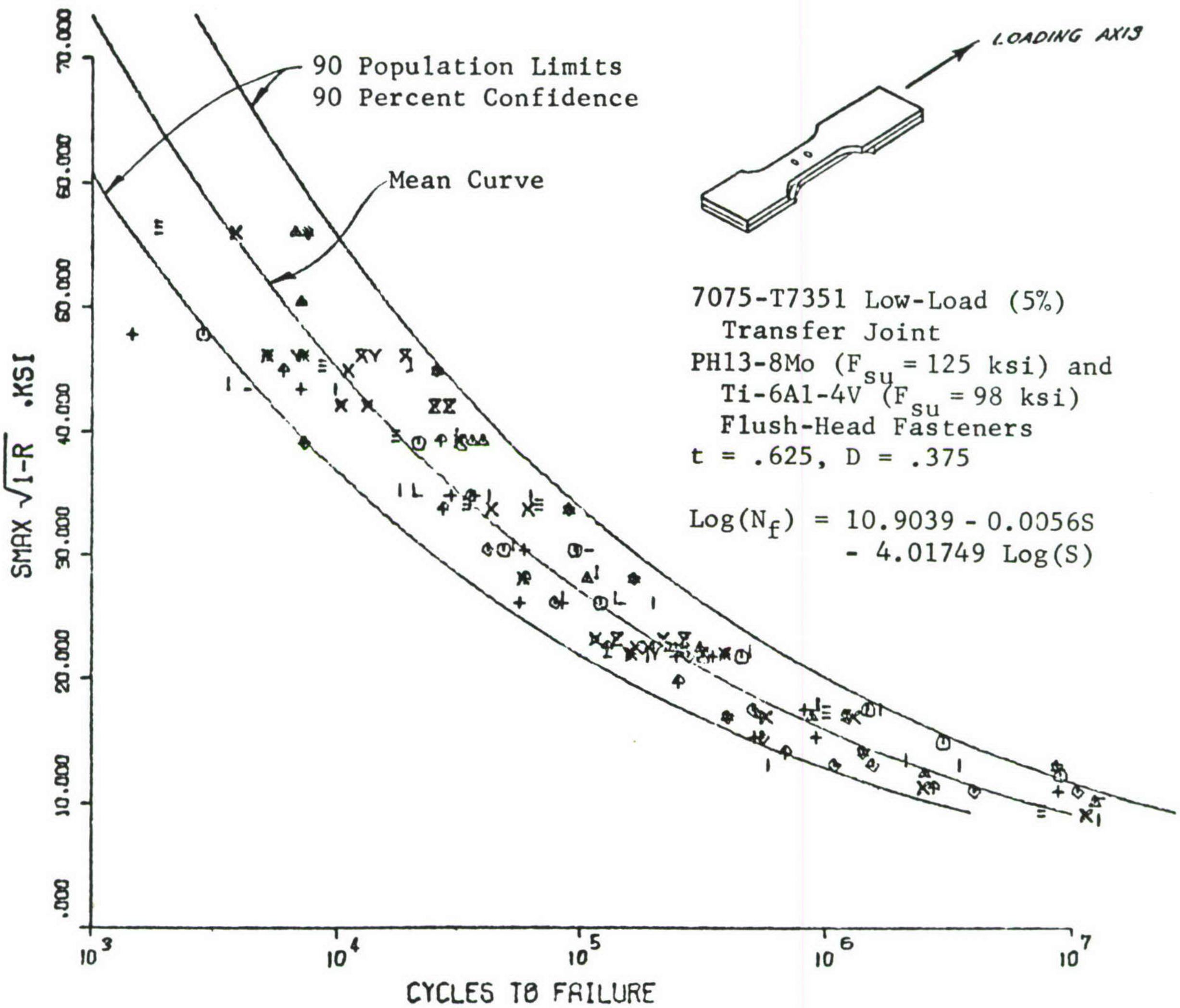
(2) Two specimens at each of two load levels for minimum and maximum installation conditions (8 specimens)

(3) Two specimens of reduced thickness at each of two load levels and two stress ratios (8 specimens)

(4) Two specimens at each of two load levels for one larger and one smaller fastener diameter than tested in (1) above (8 specimens)

(5) Two static-joint-strength specimens for each joint thickness and fastener diameter (8 specimens)

(6) Should a second fastener material be included--9 specimens at each of two stress ratios in the form of an S-N curve (18 specimens).




EFFECTS OF JOINT VARIABLES

Fastener Systems in Above Data Population

| Variable | TaperLok[a] | HiTigue[b] | Mandrelized Hole[c] |
|---|---|---|---|
| Min/Max Interference | Max > Mean | Min < Mean | Min < 90% Limit |
| .5 t/D | > Mean | > Mean | > Mean |
| Protruding Head | > Mean | > 90% Limit | > 90% Limit |
| 3/16 Diameter | > Mean | > Mean | > Mean |

[a] Manufacturer's Part Numbers: TLD100, TLV100, TLD200, TLV200-6 pins, CPL1001 nut.

[b] Manufacturer's Part Numbers: HLT35, HLT34 pins, with HL1399 collars, HLT 11, HLT10-6 pins, HL97 collars.

[c] Manufacturer's Part Numbers: ST5300 CBS sleeves, HL11, HL645, HL10, HL644 pins, HL97 collars.

FIGURE 8. PROPOSED MIL-HDBK-5 PRESENTATION FORMAT

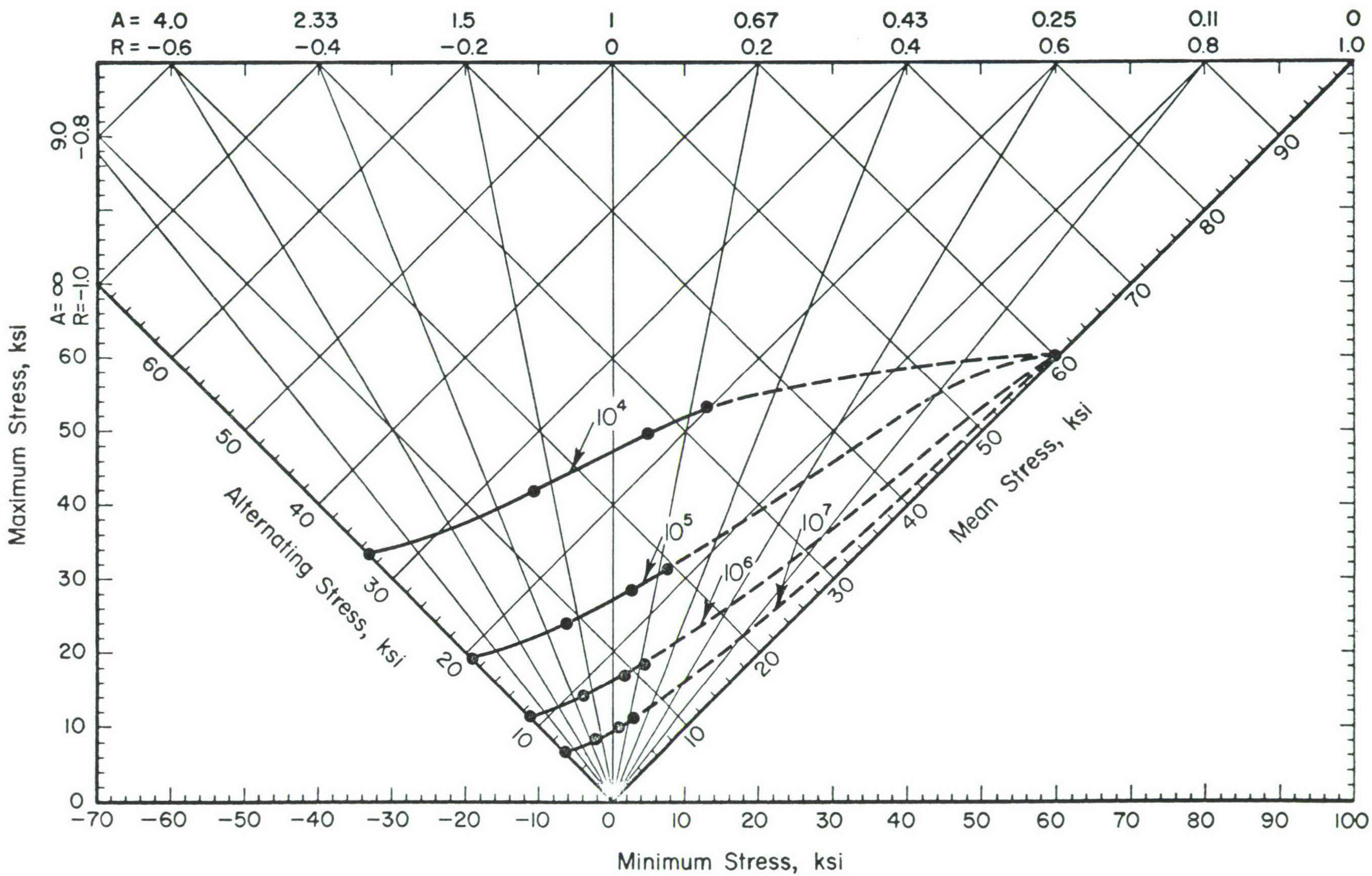



FIGURE 9. CONSTANT LIFE DIAGRAM

The above program should be repeated for each joint material and configuration proposed for inclusion in MIL-HDBK-5. The initial step in data analysis would be to determine if regression curve-fitting techniques provided a curve equation similar to that for Figure 8. If it did, the second step would be to make a direct comparison to Figure 8 and determine if the new curve belonged in the data family. A good fit would allow listing the fastener in Figure 8 along with variable-effect statements. If the fit with Figure 8 was not acceptable, a new curve would have to be added to the Handbook. In the event the Figure 9 format is selected, the constant life diagram could be constructed from information contained in the Figure 8 format.

## 12. CONCLUSIONS AND RECOMMENDATIONS

The results of this program cover a number of different areas and provide the necessary background for the initiation of several new programs. However, the following conclusions can be drawn from the results:

- Stress ratio effects can be collapsed making it possible to describe several sets of fatigue test data with differing stress ratios with one curve. This makes it possible to publish a substantial quantity of statistically confident fatigue design data in MIL-HDBK-5 in a limited amount of space and also provides for future inclusion of additional data for other fastener systems.
- Fatigue design data developed for relatively thick joints ($t/D \sim 1.5$) provides a somewhat conservative estimate of the fatigue life of thinner joints.
- Fatigue design data developed with flush-head fasteners provides a slightly conservative estimate of the fatigue lives of joints fastened with protruding-head fasteners.
- The high- and medium-load-transfer joints made up from thick sheets exhibit sufficient bending so as to cloud fastener effects.

As a result of the above, it is recommended that:

- A proposal be prepared for presentation to the MIL-HDBK-5 Coordination Group recommending inclusion of fastened joint fatigue life design data in Chapter 8 of the Handbook. It is also recommended that the presentation format be similar to that of Figure 8 of this report.
- Efforts should be directed toward the development of medium- and high-load-transfer specimens which have reduced bending stresses in thick joints. An additional objective of this effort would be the investigation of possible consolidation of data for joints with differeing levels of load transfer.
- A program be initiated to consider the possible inclusion of other fastener systems in the proposed MIL-HDBK-5 joint fatigue design data section of Chapter 8. Systems with differing functional mechanisms that might be candidates would include the "King Sizing" fastener, the Huck "EXL" system and the Cherry "CPL" nut, to name a few.

## 13. REFERENCES


(1) Military Standardization Handbook, MIL-HDBK-5, "Metallic Materials and Elements for Aerospace Vehicle Structures".

(2) Smith, C. R., "Interference Fasteners for Fatigue Life Improvement", Experimental Mechanics (August, 1965).

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(5) AFML-TR-74-10, "Sleeve Cold Working Fastener Holes", Air Force Materials Laboratory (February, 1974).

(6) Urzi, R. B., "Standardization of Fatigue Tests of Installed Fastener Systems", Lockheed-California Company Report LR25280, Naval Air Development Center Contract N62269-71-C-0450 (July, 1972).

(7) AFML-TR-73-195, "Development of Fatigue Test Standards and Mechanical Property Data on Interference-Fit Fastener Systems", Air Force Materials Laboratory (August, 1973).

(8) Rice, R. C., et al, "Consolidation of Fatigue and Fatigue-Crack-Propagation Data for Design Use", NASA CR-2586 (October, 1975).

(9) Lipson, C., and Sheth, N., Statistical Design and Analysis of Engineering Experiments, First Edition, McGraw-Hill Book Company, New York (1973), pp 79-81, Table 3.1.

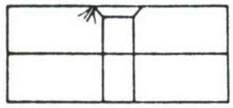
(10) Smith, K., Watson, P., and Topper, T., "A Stress-Strain Function for the Fatigue of Metals", Journal of Metals, JMLSA, vol 5, no 4 (December, 1970), pp 767-778.

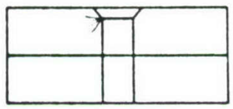
(11) Walker, K., "The Effect of Stress Ratio During Crack Propagation and Fatigue for 2024-T3 and 7075-T6 Aluminum", ASTM STP 462, American Society for Testing and Materials (1970), pp 1-14.

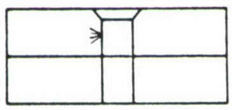
(12) Mehr, P., Spuhler, E., and Mayer, L., Unpublished data, Alcoa Alloy 7075-T73, Alcoa Green Letter, Aluminum Company of America (June, 1969).

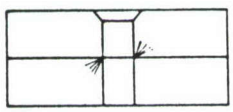
# APPENDIX A

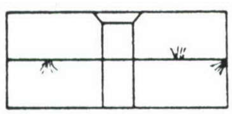
## JOINT FATIGUE TEST RESULTS

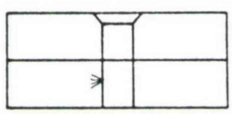
1.  TOP SHEET AT EDGE OF HEAD

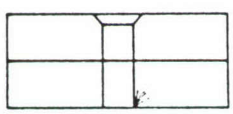
2.  TOP SHEET AT COUNTERSINK AND THROUGH-HOLE JUNCTION

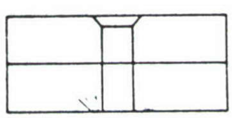
3.  TOP SHEET ALONG THROUGH HOLE

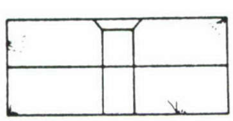
4.  FAY SURFACE AT EDGE OF HOLE

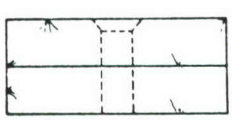
5.  FAY SURFACE--AWAY FROM HOLE

6.  PLAIN SHEET ALONG THROUGH HOLE

7.  PLAIN SHEET AT EDGE OF HOLE

7A.  PLAIN SHEET AT OUTER EDGE OF NUT

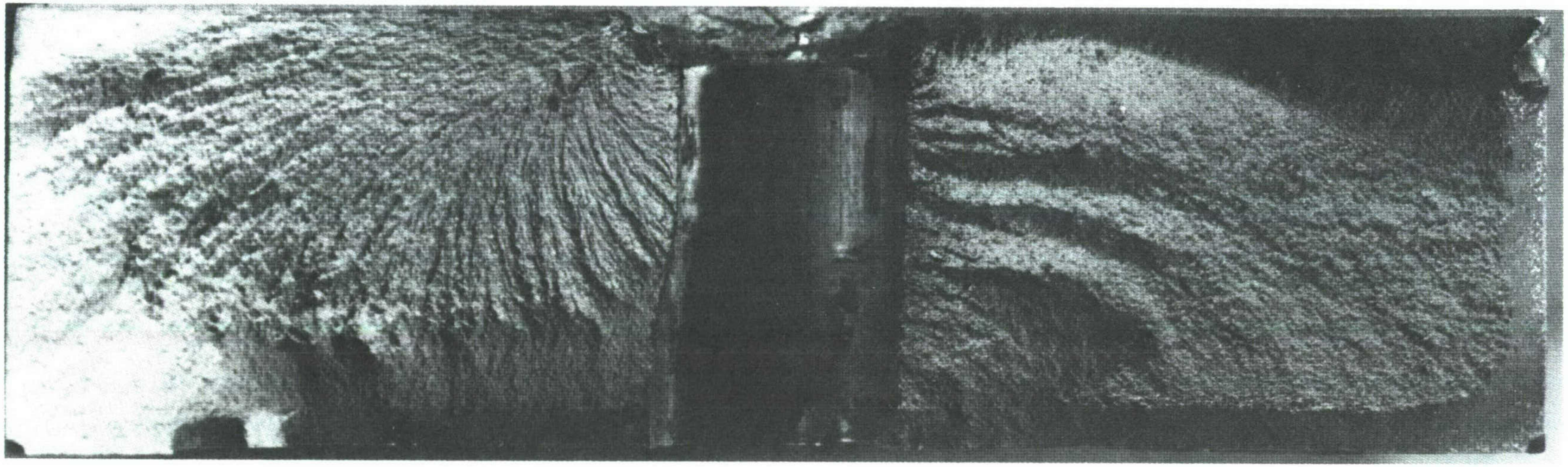
8.  SHEET SURFACE AWAY FROM HOLE (NET SECTION)

9.  GROSS SECTION

10. D.N.F. = Did Not Fail.

11. D.N.S. = Did Not Separate

FIGURE A-1. FATIGUE FAILURE MODES



7075-T7351 Joint Material

7795

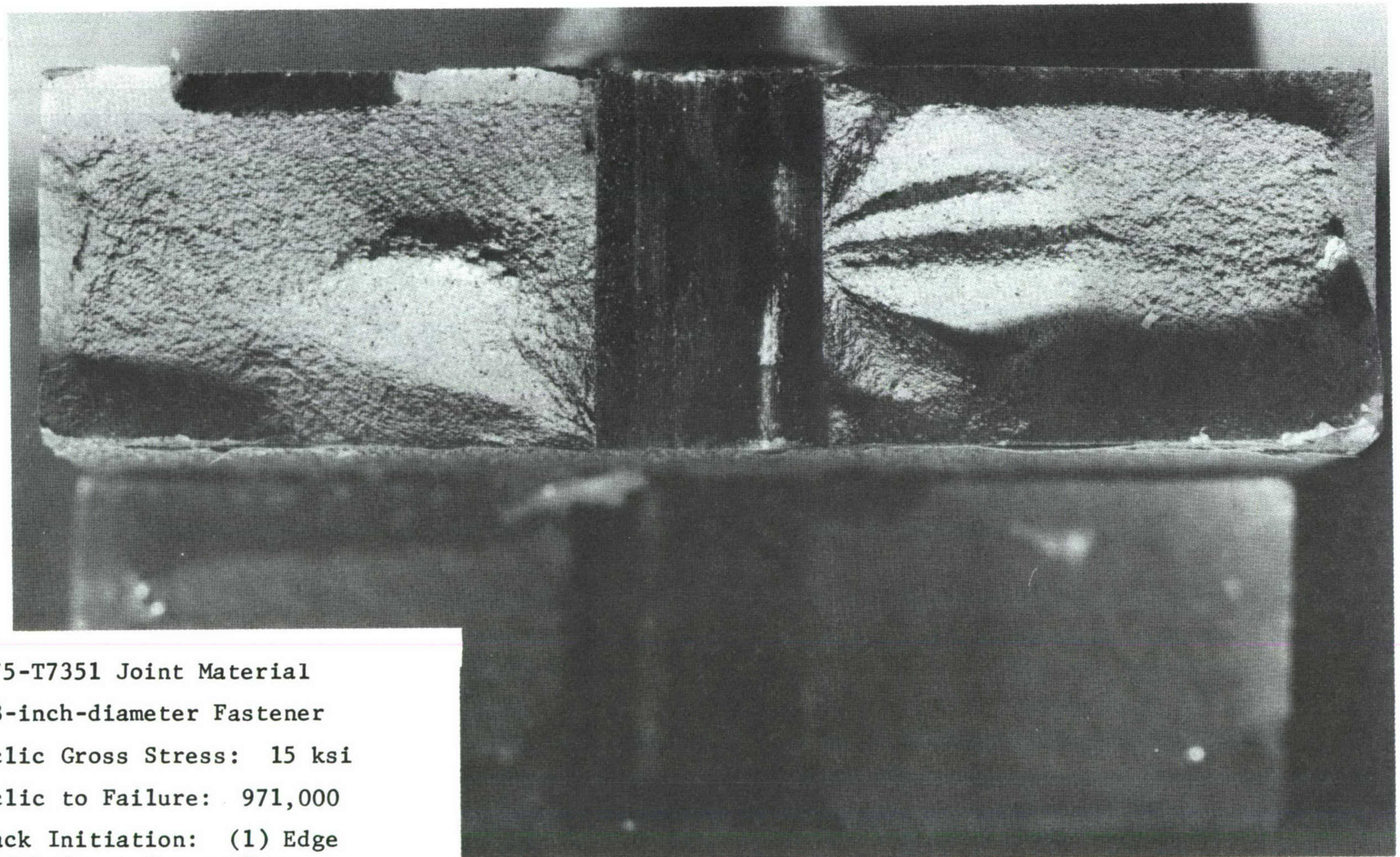
3/8-inch-diameter Fastener

Cyclic Gross Stress: 17.5 ksi

Cycles to Failure: 910,710

Crack Initiation: (1) Top sheet at edge of head, (2) Hole surface-midthickness.

FIGURE A-2. FAILED ALUMINUM LOW-LOAD TRANSFER SPECIMEN



7075-T7351 Joint Material

3/8-inch-diameter Fastener

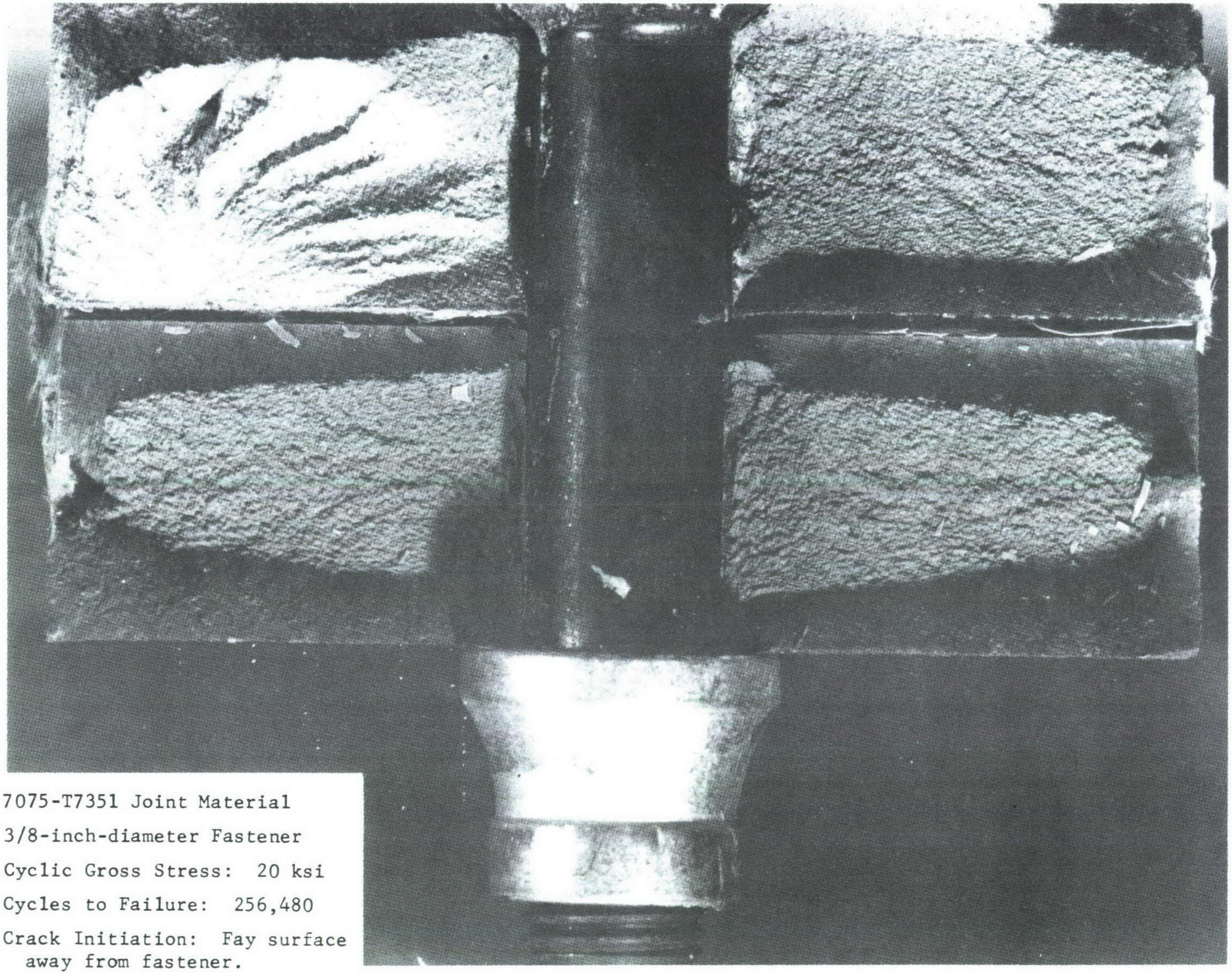
Cyclic Gross Stress: 15 ksi

Cyclic to Failure: 971,000

Crack Initiation: (1) Edge of hole at fay surface, (2) Hole surface-midthickness.

7797

FIGURE A-3. FAILED ALUMINUM LOW-LOAD TRANSFER SPECIMEN



7075-T7351 Joint Material

3/8-inch-diameter Fastener

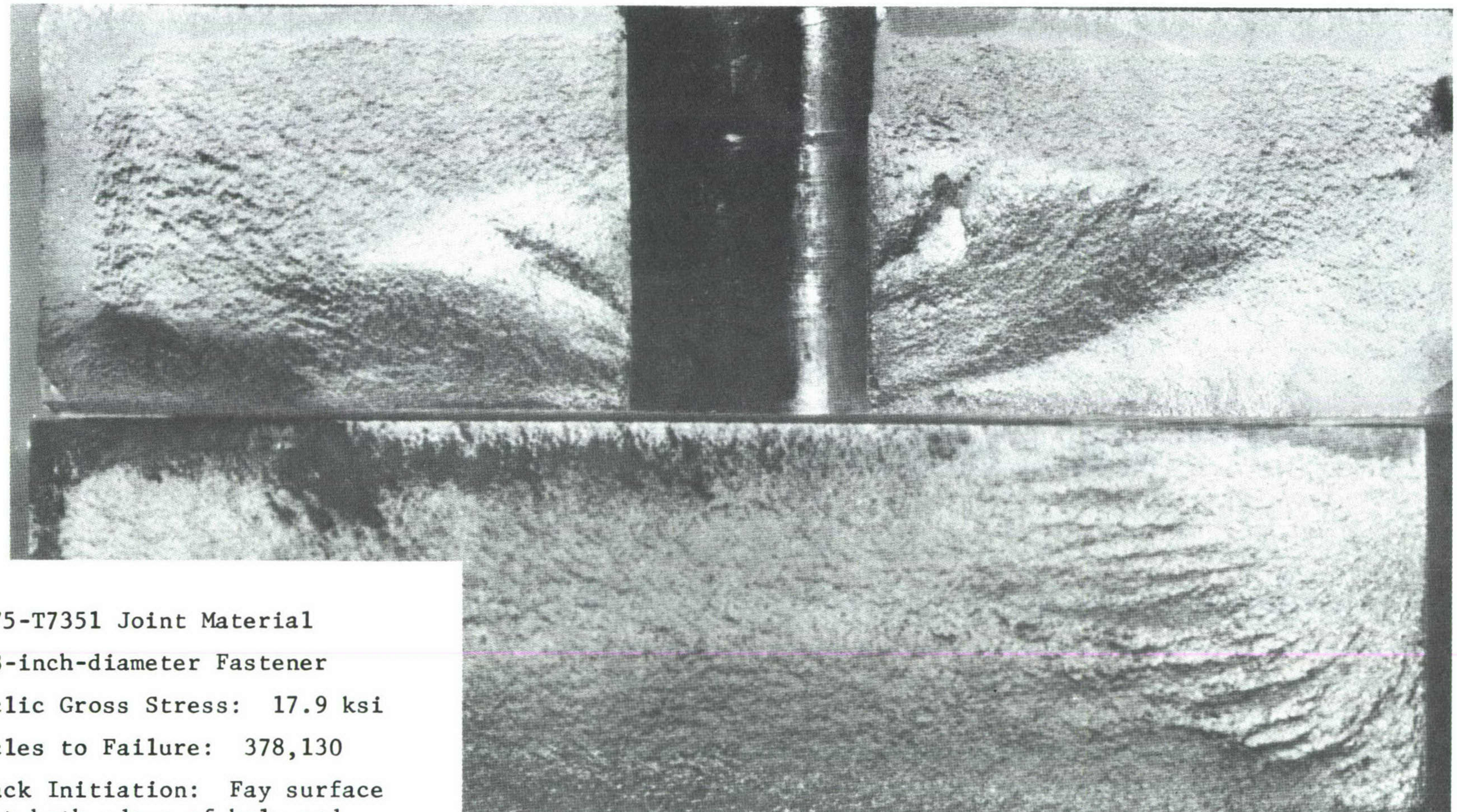
Cyclic Gross Stress: 20 ksi

Cycles to Failure: 256,480

Crack Initiation: Fay surface away from fastener.

7796

FIGURE A-4. FAILED ALUMINUM LOW-LOAD TRANSFER SPECIMEN



7075-T7351 Joint Material

3/8-inch-diameter Fastener

Cyclic Gross Stress:  17.9 ksi

Cycles to Failure:  378,130

Crack Initiation:  Fay surface at both edges of hole and gross section at edge of sheet.

7794

FIGURE A-5.  FAILED ALUMINUM LOW-LOAD TRANSFER SPECIMEN

TABLE A-1. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | TDF6DA2 |
| **Fastener System:** | TLD100-6 Pin, TLN1001-CPL-6 Nut |
| **Interference Fit:** | 0.004 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, A-286 Nut |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DA2-13 | 35 | 95,130 | 8 | |
| -12 | 45 | 21,880 | 7 | |
| -11 | 55 | 2,820 | 6 | |
| -9 | 25 | 453,290 | 4 | |
| -8 | 30 | 120,530 | 4 | |
| -7 | 35 | 49,060 | 4 | |
| -6 | 45 | 32,721 | 4 | |
| -5 | 20 | 1,480,070 | 4 | |
| -3 | 17 | 2,963,390 | 4 | |
| -2 | 14 | 8,894,490 | 7 | |
| -1 | 25 | 316,710 | 8 | |
| -14 | 20 | 4,411,600 | 6 | |

(a) See failure mode description.

TABLE A-2. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS (Minimum and Maximum Interference Conditions)

**Specimen Designation:** TDF6DA3
**Fastener System:** TLD100-6 pin, TLN1001-CPL-6 nut
**Interference Fit:** 0.003 (minimum) and 0.006 (maximum) inch
**Fastener Material:** PH13-8Mo pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| TDF6DA3-1 | 23.1 | 354,260 | 1 | Minimum Interference |
| -3 | 48.5 | 13,680 | 4 | " " |
| -9 | 48.5 | 26,480 | 4 | Maximum Interference |
| -10 | 23.1 | 377,340 | 4 | " " |
| -11 | 23.1 | 1,547,620 | 4 | " " |
| -12 | 23.1 | 520,950 | 9 | " " |

(a) See failure mode description.

TABLE A-3. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF6DA4
**Fastener System:** TLD100-6 Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = - 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DA4-2 | 15 | 878,720 | 7 | |
| -3 | 25 | 106,240 | 1 | |
| -4 | 20 | 306,390 | 9 | |
| -1 | 35 | 40,000 | 9 | |
| -5 | 45 | 7,170 | 4 | |
| -6 | 20 | 230,090 | 4 | |
| -7 | 35 | 36,030 | 2 | |
| -11 | 11 | 2,493,270 | 4 | |
| -12 | 9 | 12,242,940 | D.N.F. | |
| -13 | 50 | 6,740 | 4 | |

(a) See failure mode description.

TABLE A-4. 3/8 INCH STEEL TAPERLOK, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | TDF6DA5 |
| **Fastener System:** | TLD100-6-Pin, TLN1001-CPL-6 Nut |
| **Interference Fit:** | 0.004 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, A-286 Nut |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| TDF6DA5-4 | 48.5 | 33,230 | 1 | |
| -3 | 48.5 | 19,980 | 4 | |
| -12 | 34.6 | 136,340 | 2 | |
| -5 | 34.6 | 112,640 | 5 | |
| -1 | 23.1 | 1,685,200 | 4 | |
| -7 | 23.1 | 1,833,560 | 2 | |
| | | R = - 0.25 | | |
| TDF6DA5-10 | 37.6 | 30,190 | 1 | |
| -11 | 37.6 | 31,590 | 1 | |
| -9 | 26.8 | 123,366 | 4 | |
| -8 | 26.8 | 70,310 | 1 | |
| -2 | 17.9 | 554,920 | 4 | |
| -6 | 17.9 | 377,790 | 9 | Grip Failure |

(a) See failure mode description.

TABLE A-5. 3/16 INCH STEEL TAPERLOK, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF3DA6
**Fastener System:** TLD100-3 Pin, TLN1001-CPL-3 Nut
**Interference Fit:** 0.0025 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.4

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| TDF3DA6-3 | 48.5 | 30,950 | 3 | |
| -7 | 48.5 | 19,030 | 3 | |
| -5 | 48.5 | 29,940 | 3 | |
| -2 | 23.1 | 786,640 | 6 | |
| -1 | 23.1 | 828,700 | 4 | |
| -8 | 23.1 | 397,810 | 9 | Grip Failure |

(a) See failure mode description.

TABLE A-6. 3/8 INCH STEEL TAPERLOK, 7075-T7351 HIGH-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | TDF6MA9 |
| **Fastener System:** | TLD100-6 Pin, TLD1001-CPL-6 Nut |
| **Interference Fit:** | 0.004 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, A-286 Nut |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6MA9-14 | 12.5 | 275,290 | 9 | |
| -13 | 15 | 275,000 | 4 | |
| -12 | 25 | 11,650 | 4 | |
| -10 | 20 | 44,840 | 4 | |
| -9 | 10 | 1,609,940 | 9 | |
| -15 | 7.5 | 651,290 | 4 | |

(a) See failure mode description.

TABLE A-7. 3/8 INCH STEEL TAPERLOK, 7075-T7351 HIGH-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF6MA10
**Fastener System:** TLD100-6 Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = - 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| TDF6MA10-9 | 5 | 2,333,330 | 9 | |
| -8 | 5 | 1,880,510 | 9 | |
| -7 | 7.5 | 824,910 | 9 | |
| -6 | 25 | 7,160 | 4 | |
| -4 | 10 | 259,030 | 9 | |
| -3 | 12.5 | 212,250 | 4 | |
| -2 | 15 | 54,540 | 4 | |
| -1 | 20 | 35,000 | 9 | |

(a) See failure mode description.

TABLE A-8. 3/8 INCH TITANIUM TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TVF6DA22
**Fastener System:** TLV100-6 Pin, TLN1001L-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** 6AL-4V Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| TVF6DA22-12 | 15 | 3,441,330 | 4 | |
| -8 | 30 | 197,930 | 9 | |
| -9 | 20 | 1,659,490 | 7A | |
| -10 | 20 | 1,454,480 | 7A | |
| -2 | 50 | 9,890 | 3 | |
| -1 | 10 | 12,620,850 | D.N.F. | |
| -5 | 35 | 97,570 | 5 | |
| -3 | 40 | 63,100 | 6 | |
| -7 | 15 | 580,600 | 8 | |
| -6 | 25 | 188,220 | 8 | |
| -4 | 17.5 | 540,630 | 8 | |
| -12 | 15 | 3,441,340 | 4 | |
| -11 | 40 | 42,470 | 5 | |

(a) See failure mode description.

TABLE A-9. 3/8 INCH TITANIUM TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | TVF6DA23 |
| **Fastener System:** | TLV100-6 Pin, TLN1001L-6 Nut |
| **Interference Fit:** | 0.004 Inch Interference |
| **Fastener Material:** | 6AL-4V Pin, A-286 Nut |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TVF6DA23-4 | 20 | 245,552 | 5 | |
| -2 | 50 | 7,530 | 6 | |
| -1 | 15 | 397,800 | 4 & 7A | |
| -7 | 40 | 25,820 | 2 | |
| -3 | 30 | 89,420 | 5 | |
| -5 | 25 | 166,270 | 5 | |
| -6 | 12.5 | 1,412,930 | 4 | |
| -9 | 11.5 | 8,594,130 | 9 | Grip Failure |
| -8 | 15 | 1,215,870 | 4 | |

(a) See failure mode description.

TABLE A-10. 3/8 INCH TITANIUM TAPERLOK, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TVF6DA25
**Fastener System:** TLV100-6 Pin, TLN1001L-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** 6AL-4V Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 0.5

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| TVF6DA25-1 | 48.5 | 12,010 | 2 | |
| -2 | 34.6 | 142,470 | 6 | |
| -7 | 23.1 | 329,860 | 2 | |
| -8 | 48.5 | 15,280 | 2 | |
| -9 | 34.6 | 159,500 | 6 | |
| -11 | 23.1 | 681,810 | 2 | |
| | | R = - 0.25 | | |
| TVF6DA25-3 | 17.9 | 292,890 | 9 | |
| -4 | 26.8 | 33,490 | 2 | |
| -5 | 37.6 | 23,280 | 2 | |
| -6 | 26.8 | 52,910 | 2 | |
| -10 | 37.6 | 15,400 | 8 | |
| -12 | 17.9 | 351,230 | 2 | |

(a) See failure mode description.

TABLE A-11. 3/8 INCH STEEL TAPERLOK, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

Specimen Designation: TDF6DT31
Fastener System: TLD100-6 Pin, TLN1001L-6 Nut
Interference Fit: 0.004 Inch Interference
Fastener Material: PH13-8Mo Pin, A-286 Nut
Stress Ratio, $S_{min}/S_{max}$: R = + 0.25
Thickness to Diameter Ratio: t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DT31-8 | 58 | 819,230 | 9 | Grip Failure |
| -9 | 70 | 122,050 | D.N.S. | |
| -2 | 60 | 293,650 | 6 | |
| -7 | 60 | 730,740 | 3 & 6 | |
| -10 | 70 | 85,030 | 7 | |
| -4 | 90 | 12,380 | 2 | |
| -3 | 80 | 21,620 | 3 | |
| -6 | 50 | 3,463,770 | D.N.F. | |
| -5 | 60 | 647,000 | 4 | |

(a) See failure mode description.

TABLE A-12. 3/8 INCH STEEL TAPERLOK, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF6DT33
**Fastener System:** TLD100-6 Pin, TLN1001L- Nut
**Interference Fit:** 0.003 (Minimum) and 0.006 (Maximum) Inch
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DT33-6 | 55 | 839,470 | 4 | Minimum Interference |
| -8 | 55 | 914,090 | 4 | " " |
| -2 | 55 | 331,620 | 2 | Maximum Interference |
| -4 | 55 | 391,950 | 6 | " " |
| -1 | 80 | 111,670 | 1 | " " |

(a) See failure mode description.

TABLE A-13. 3/8 INCH TITANIUM TAPERLOK, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TVF6DT35
**Fastener System:** TLV100-6 Pin, TLN1001L-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** 6AL-4V Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 0.6

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| TVF6DT35-5 | 80 | 66,630 | 3 | |
| -1 | 80 | 58,710 | 6 | |
| -3 | 65 | 175,790 | 6 | |
| -4 | 65 | 143,390 | 6 | |
| -6 | 55 | 1,493,130 | 3 | |
| -2 | 55 | 1,836,750 | D.N.F. | |

(a) See failure mode description.

TABLE A-14. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDP6DA43
**Fastener System:** TLD200-6 Protruding Head Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| TDP6DA43-1 | 23.1 | 488,940 | 4 | |
| -3 | 23.1 | 235,680 | 4 | |
| -4 | 34.6 | 144,320 | 2 | |
| -5 | 34.6 | 52,590 | 6 | |
| -2 | 48.5 | 12,870 | 6 | |
| -7 | 48.5 | 18,270 | 6 | |
| | | R = - 0.25 | | |
| TDP6DA43-6 | 17.9 | 421,710 | 7A | |
| -11 | 17.9 | 231,750 | 4 | |
| -9 | 26.8 | 80,260 | 6 | |
| -12 | 26.8 | 96,590 | 4 | |
| -8 | 37.6 | 20,600 | 3 | |
| -10 | 37.6 | 14,760 | 4 | |

(a) See failure mode description.

TABLE A-15. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDP6DA45
**Fastener System:** TLD200-6 Protruding Head Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 0.5

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| TDP6DA45-2A | 23.1 | 609,580 | 7A | |
| -11A | 23.1 | 545,980 | 3 | |
| -4A | 34.6 | 149,740 | 7A | |
| -8A | 34.6 | 120,200 | 7A | |
| -12A | 48.5 | 21,840 | 6 | |
| -1A | 48.5 | 10,820 | 2 | |
| | | R = - 0.25 | | |
| TDP6DA45-9A | 17.9 | 482,810 | 4 & 6 | |
| -3A | 17.9 | 521,980 | 9 | |
| -5 | 26.8 | 147,220 | 7A | |
| -6 | 26.8 | 111,790 | 6 | |
| -10A | 37.6 | 21,870 | 4 | |
| -7A | 37.6 | 15,750 | 4 | |

(a) See failure mode description.

TABLE A-16. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF6DA48
**Fastener System:** TLD100-6 Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.1
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DA48-4A | 48.5 | 12,670 | 6 | |
| -2A | 48.5 | 19,160 | 4 | |
| -3A | 23.1 | 255,010 | 9 | |
| -1A | 23.1 | 314,230 | 9 | |

(a) See failure mode description.

TABLE A-17. 3/8 INCH STEEL TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** TDF6DA49
**Fastener System:** TLD100-6 Pin, TLN1001-CPL-6 Nut
**Interference Fit:** 0.004 Inch Interference
**Fastener Material:** PH13-8Mo Pin, A-286 Nut
**Stress Ratio, $S_{min}/S_{max}$:** R = - 1.0
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| TDF6DA49-2A | 16.3 | 265,520 | | 1 & 4 |
| -1A | 16.3 | 140,420 | | D.N.S. |
| -3 | 29.7 | 25,450 | | 4 |
| -4A | 29.7 | 28,920 | | 6 |

(a) See failure mode description.

TABLE A-18. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DA2 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF6DA2-1 | 20 | 822,670 | D.N.S. | |
| -2 | 30 | 84,730 | D.N.S. | |
| -3 | 25 | 246,100 | 4 | |
| -4 | 35 | 59,550 | D.N.S. | |
| -5 | 40 | 37,140 | D.N.S. | |
| -6 | 25 | 346,280 | 4 | |
| -7 | 50 | 7,130 | 4 | |
| -8 | 40 | 29,880 | D.N.S. | |
| -9 | 17.5 | 508,260 | 9 | |
| -10 | 17.5 | 910,710 | 1 | |
| -11 | 12.5 | 8,636,110 | 9 | Grip Failure |
| -12 | 30 | 56,850 | 4 | |
| -13 | 45 | 7,290 | 4 | |
| -15 | 55 | 1,440 | 6 | |

(a) See failure mode description.

TABLE A-19. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS, MINIMUM AND MAXIMUM INTERFERENCE CONDITIONS

**Specimen Designation:** SDF6DA3
**Fastener System:** HLT35-12 Pin, HL1399 Collar
**Interference Fit:** 0.002 (Minimum) and 0.006 (Maximum) Inch
**Fastener Material:** PH13-8Mo Pin, Steel Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF6DA3-1 | 36.4 | 26,220 | 4 | Minimum Interference |
| -2 | 36.4 | 14,920 | 4 | " " |
| -3 | 36.4 | 20,980 | 6 | " " |
| -4 | 23.1 | 290,570 | 9 | " " |
| -5 | 23.1 | 447,950 | 6 | " " |
| -6 | 23.1 | 207,200 | 6 | " " |
| -7 | 36.4 | 35,540 | 4 | Maximum Interference |
| -8 | 34.6 | 72,350 | 7A | " " |
| -9 | 36.4 | 37,110 | 4 | " " |
| -10 | 23.1 | 306,230 | 5 | " " |
| -11 | 23.1 | 543,960 | 8 | " " |
| -12 | 23.1 | 311,080 | 5 | " " |

(a) See failure mode description.

TABLE A-20. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DA4 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF6DA4-1 | 30 | 43,460 | 6 | |
| -2 | 15 | 1,295,710 | 9 | Grip Failure |
| -3 | 40 | 11,220 | 3 | |
| -4 | 20 | 169,910 | 9 | |
| -5 | 20 | 189,620 | 5 | |
| -6 | 35 | 32,430 | 4 | |
| -7 | 25 | 58,790 | 3 | |
| -8 | 50 | 3,830 | 6 | |
| -9 | 8 | 11,361,420 | D.N.F. | |
| -10 | 10 | 2,482,450 | 6 | |
| -11 | 15 | 570,180 | 1 | |
| -12 | 30 | 61,230 | 1 | |

(a) See failure mode description.

TABLE A-21. 3/8 INCH STEEL HITIGUE, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DA5 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| SDF6DA5-1 | 23.1 | 992,490 | 2 | |
| -2 | 48.5 | 19,320 | 6 | |
| -5 | 23.1 | 1,279,080 | 4 | |
| -8 | 34.6 | 177,840 | 8 | |
| -11 | 34.6 | 212,280 | 9 | |
| -12 | 48.5 | 19,430 | 2 | |
| | | R = - 0.25 | | |
| SDF6DA5-4 | 48.5 | 6,220 | 1 | |
| -6 | 34.6 | 45,100 | 1 | |
| -7 | 37.6 | 23,830 | 5 | |
| -10 | 17.9 | 623,030 | 4 | |
| -13 | 17.9 | 758,950 | 5 | |
| -14 | 26.8 | 240,100 | 8 | |

(a) See failure mode description.

TABLE A-22. 3/16 INCH STEEL HITIGUE, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF3DA6 |
| **Fastener System:** | HLT35-6 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.4 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF3DA6-4 | 23.1 | 1,038,180 | 2 | |
| -2A | 48.5 | 5,850 | 6 | |
| -1A | 48.5 | 8,610 | 6 | |
| -7A | 23.1 | 1,038,740 | 1 | |
| -8A | 48.5 | 7,060 | 3 | |
| -6A | 23.1 | 774,320 | 4 | |

(a) See failure mode description.

TABLE A-22A. 1/2 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF8DA7 |
| **Fastener System:** | HLT35-16 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = +0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SDF8DA7-5 | 23.1 | 375,170 | 1 & 3 | |
| -7 | 23.1 | 312.460 | 3 & 4 | |

(a) See failure mode description.

TABLE A-23. 3/8 INCH STEEL HITIGUE, 7075-T7351 HIGH-LOAD TRANSFER SPECIMENS

**Specimen Designation:** SDF6MA9
**Fastener System:** HLT35-12 Pin, HL1399 Collar
**Interference Fit:** 0.0045 Inch Interference
**Fastener Material:** PH13-8Mo Pin, Steel Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SDF6MA9-14 | 7.5 | 1,647,380 | 9 | |
| -11 | 20 | 26,840 | 4 | |
| -12 | 20 | 27,450 | 4 | |
| -10 | 15 | 112,670 | 4 | |
| -13 | 10 | 310,660 | 4 | |
| -15 | 5 | 4,320,570 | 9 | |
| -9 | 25 | 6,750 | 4 | |

(a) See failure mode description.

TABLE A-24. 3/8 INCH STEEL HITIGUE, 7075-T7351 HIGH-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6MA10 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Tolerance |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SDF6MA10-1 | 7.5 | 406,050 | 9 | |
| -2 | 15 | 38,020 | 9 | |
| -3 | 10 | 158,490 | 4 | |
| -4 | 20 | 16,490 | 4 | |
| -5 | 12.5 | 82,050 | 4 | |
| -6 | 10 | 366,560 | 9 | |
| -7 | 5 | 3,340,150 | 9 | |
| -8 | 25 | 2,850 | 4 | |
| -11 | 5 | 1,395,900 | 9 | |
| -10 | 20 | 18,220 | 4 | |

(a) See failure mode description.

TABLE A-25. 3/8 INCH TITANIUM HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** SVF6DA22
**Fastener System:** HLT11-12 Pin, HL95 Collar
**Interference Fit:** 0.0045 Inch Interference
**Fastener Material:** 6AL-4V Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SVF6DA22-1 | 40 | 27,900 | 4 | |
| -3 | 25 | 126,180 | 6 | |
| -4 | 50 | 4,200 | 3 | |
| -5 | 20 | 1,183,820 | 7A | |
| -10 | 30 | 143,680 | 4 | |
| -12 | 25 | 234.120 | 4 | |
| -9 | 35 | 105,790 | 4 | |
| -2 | 15 | 1,457,370 | 2 | |
| -8 | 15 | 1,084,370 | 7A | |
| -6 | 12 | 12,551,720 | D.N.F. | |
| -7 | 40 | 21,300 | 4 | |
| -11 | 20 | 876,700 | 9 | Grip Failure |

(a) See failure mode description.

TABLE A-26. 3/8 INCH TITANIUM HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

Specimen Designation: SVF6DA23
Fastener System: HLT11-12 Pin, HL97 Collar
Interference Fit: 0.0045 Inch Interference
Fastener Material: 6AL-4V Pin, A-286 Collar
Stress Ratio, $S_{min}/S_{max}$: R = - 0.25
Thickness to Diameter Ratio: t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SVF6DA23-4 | 20 | 256,480 | 5 | |
| -6 | 30 | 66,010 | 5 | |
| -3 | 15 | 431,080 | 9 | Grip Failure |
| -2 | 15 | 979,470 | 7A | |
| -8 | 40 | 8,490 | 6 | |
| -7 | 35 | 17,170 | 6 | |
| -9 | 8 | 7,240,320 | 2 & 4 | |
| -5 | 50 | 1,790 | 6 | |
| -1 | 30 | 33,280 | 4 | |

(a) See failure mode description.

TABLE A-27. 3/8 INCH TITANIUM HITIGUE, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SVF6DA25 |
| **Fastener System:** | HLT11-12 Pin, HL97 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | 6AL-4V Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| SVF6DA25-1 | 34.6 | 127,810 | 5 | |
| -3 | 48.5 | 25,780 | 1 | |
| -4 | 48.5 | 12,220 | 6 | |
| -6 | 23.1 | 835,580 | 2 | |
| -7 | 23.1 | 862,520 | 1 | |
| -8 | 34.6 | 120,720 | 1 | |
| | | R = - 0.25 | | |
| SVF6DA25-2 | 26.8 | 85,190 | 5 | |
| -5 | 17.9 | 546,810 | 9 | Grip Failure |
| -9 | 17.9 | 669,510 | 4 | |
| -10 | 37.6 | 25,540 | 1 | |
| -11 | 37.6 | 28,670 | 1 | |
| -12 | 26.8 | 90,620 | 1 | |

(a) See failure mode description.

TABLE A-28. 3/8 INCH STEEL HITIGUE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DT33 |
| **Fastener System:** | HLT35-12 Pin, HL-97 Collar |
| **Interference Fit:** | 0.002 (Minimum) and 0.006 (Maximum) Inch |
| **Fastener Material:** | PH13-8Mo Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SDF6DT33-5 | 55 | 168,260 | 3 | Minimum Interference |
| -8 | 55 | 213,200 | 3 | " " |
| -2 | 55 | 162,570 | 4 | Maximum Interference |
| -1 | 55 | 245,530 | 4 | " " |

(a) See failure mode description.

TABLE A-29. 3/8 INCH STEEL HITIGUE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DT35 |
| **Fastener System:** | HLT35-12 Pin, HL95 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8MO Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.6 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SDF6DT35-5 | 80 | 25,810 | D.N.S. | |
| -2 | 80 | 54,120 | 1 & 2 | |
| -1 | 65 | 77,290 | 2 | |
| -3 | 65 | 73,130 | 6 | |
| -6 | 55 | 141,990 | 4 | |
| -4 | 55 | 90,550 | 6 | |

(a) See failure mode description.

TABLE A-30. 3/8 INCH TITANIUM HITIGUE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SVF6DT41 |
| **Fastener System:** | HLT11-12 Pin, HL-97 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | 6AL-4V Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| SVF6DT41-3 | 65 | 79,370 | 4 | |
| -6 | 65 | 72,870 | 4 | |
| -8 | 55 | 184,460 | 2 | |
| -4A | 55 | 269,820 | D.N.S. | |

(a) See failure mode description.

TABLE A-31. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDP6DA43 |
| **Fastener System:** | HLT 34-12 Protruding Head Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| SDP6DA43-9 | 48.5 | 17,550 | 4 | |
| -7 | 48.5 | 26,380 | 4 | |
| -4 | 34.6 | 54,250 | 5 | |
| -6 | 34.6 | 72,400 | 1 | |
| -2 | 23.1 | 309,790 | 5 | |
| -5 | 23.1 | 206,870 | 8 | |
| | | R = - 0.25 | | |
| SDP6DA43-10 | 37.6 | 31,490 | 5 | |
| -1 | 37.6 | 38,940 | 1 | |
| -11 | 26.8 | 96,440 | 8 | |
| -3 | 26.8 | 73,600 | 4 | |
| -8 | 17.9 | 364,980 | 8 | |
| -12 | 17.9 | 378,130 | 4 | |

(a) See failure mode description.

TABLE A-32. 3/8 INCH STEEL HITIGUE, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** SDP6DA45
**Fastener System:** HLT34-12 Protruding Head Pin, HL1399 Collar
**Interference Fit:** 0.0045 Inch Interference
**Fastener Material:** PH13-8Mo Pin, Steel Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 0.5

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| SDP6DA45-9 | 23.1 | 1,346,340 | 4 | |
| -7 | 23.1 | 330,560 | 4 | |
| -3 | 34.6 | 131,100 | 9 | |
| -10 | 34.6 | 106.610 | 2 | |
| -12 | 48.5 | 14,840 | 4 | |
| -5 | 48.5 | 19,590 | 7 | |
| | | R = - 0.25 | | |
| SDP6DA45-11 | 17.9 | 1,064,860 | 7 | |
| -1 | 17.9 | 645,230 | 5 | |
| -6 | 26.8 | 102,840 | 6 | |
| -4 | 26.8 | 96,680 | 6 | |
| -8 | 37.6 | 40,400 | 5 | |
| -2 | 37.6 | 37,220 | 3 | |

(a) See failure mode description.

TABLE A-33. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DA48 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.1 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF6DA48-2 | 23.1 | 158,630 | 6 | |
| -4 | 23.1 | 200,940 | 2 | |
| -3 | 48.5 | 6,800 | 6 | |
| -1 | 48.5 | 14,460 | 4 | |

(a) See failure mode description.

TABLE A-34. 3/8 INCH STEEL HITIGUE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | SDF6DA49 |
| **Fastener System:** | HLT35-12 Pin, HL1399 Collar |
| **Interference Fit:** | 0.0045 Inch Interference |
| **Fastener Material:** | PH13-8Mo Pin, Steel Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = - 1.0 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| SDF6DA49-1 | 16.3 | 115,130 | 6 | |
| -4 | 29.7 | 10,410 | 4 | |
| -3 | 16.3 | 217,530 | 4 | |
| -2 | 29.7 | 13,520 | 6 | |

(a) See failure mode description.

TABLE A-35. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** MDF6DA2
**Fastener System:** ST5300-CBS-12 Sleeve, HL645 Pin, HL97 Collar
**Interference Fit:** 0.018 Inch Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, PH13-8Mo Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| MDF6DA2-1 | 35 | 42,250 | 5 | |
| -2 | 20 | 502,860 | 4 | |
| -3 | 17.5 | 551,020 | 9 | Grip Failure |
| -4 | 30 | 79,540 | 4 | |
| -5 | 12.5 | 10,401,850 | D.N.F. | |
| -6 | 12.5 | 1,823,010 | 9 | Grip Failure |
| -7 | 15 | 1,543,720 | 6 | |
| -8 | 25 | 274,720 | 8 | |
| -9 | 40 | 35,840 | 3 & 6 | |
| -12 | 12.5 | 3,966,830 | 9 | Grip Failure |
| -13 | 15 | 1,077,450 | 4 | |
| -14 | 45 | 7,360 | 3 & 6 | |

(a) See failure mode description.

TABLE A-36. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS, MINIMUM INTERFERENCE CONDITION

**Specimen Designation:** MDF6DA3
**Fastener System:** ST5300-CBS-12 Sleeve, HL645 Pin, HL97 Collar
**Interference Fit:** 0.015 Inch Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, PH13-8Mo Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DA3-2 | 23.1 | 154,690 | 8 | |
| -7 | 23.1 | 361,020 | 8 | |
| -8 | 48.5 | 3,440 | 3 & 6 | |
| -10 | 23.1 | 297,440 | 5 | |
| -11 | 48.5 | 4,200 | 3 & 6 | |
| -4 | 48.5 | 4,660 | 6 | |

(a) See failure mode description.

TABLE A-37. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| Specimen Designation: | MDF6DA4 |
| Fastener System: | ST5300-CBS-12 Sleeve, HL645 Pin, HL97 Collar |
| Interference Fit: | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| Fastener Material: | A-286 Sleeve, PH13-8Mo Pin, A-286 Collar |
| Stress Ratio, $S_{min}/S_{max}$: | R = - 0.25 |
| Thickness to Diameter Ratio: | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DA4-1 | 15 | 542,770 | 9 | Grip Failure |
| -2 | 35 | 26,930 | 3 & 6 | |
| -4 | 17.5 | 249,410 | 3 & 6 | |
| -5 | 20 | 198,560 | 3 | |
| -6 | 12.5 | 681,050 | 9 | Grip Failure |
| -7 | 25 | 59,070 | 3 & 6 | |
| -8 | 20 | 128,650 | 8 | |
| -9 | 40 | 6,020 | 3 & 6 | |
| -10 | 10 | 2,698,610 | 9 | Grip Failure |
| -11 | 30 | 27,480 | 3 & 6 | |
| -12 | 35 | 32,500 | 3 & 6 | |

(a) See failure mode description.

TABLE A-38. 3/8 INCH SPLIT SLEEVE, 7075-T73 LOW-LOAD TRANSFER JOINTS

**Specimen Designation:** MDF6DA5
**Fastener System:** ST5300-CBS-12 Sleeve, HL645 Pin, HL97 Collar
**Interference Fit:** 0.018 Inch Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, PH13-8Mo Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 0.5

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| MDF6DA5-9 | 48.5 | 25,076 | 6 | |
| -1 | 48.5 | 14,920 | 6 | |
| -11 | 34.6 | 159,830 | 5 | |
| -13 | 34.6 | 145,620 | 8 | |
| -2 | 23.1 | 503,340 | 3 | |
| -3 | 23.1 | 821,710 | 3 | |
| | | R = - 0.25 | | |
| MDF6DA5-5 | 37.6 | 39,580 | 5 | |
| -8 | 37.6 | 31,540 | 6 | |
| -12 | 26.8 | 67,060 | 8 | |
| -7 | 26.8 | 87,160 | 6 | |
| -4 | 17.9 | 657,580 | 4 | |
| -6 | 17.9 | 781,850 | 4 | |

(a) See failure mode description.

TABLE A-39. 3/16 INCH SPLIT SLEEVE, 7075-T73 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MDF3DA6 |
| **Fastener System:** | ST5300-CBS-6 Sleeve, HL645 Pin, HL97 Collar |
| **Interference Fit:** | 0.012 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, PH13-8Mo Pin, A-286 Nut |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 1.4 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF3DA6-5 | 23.1 | 1,796,750 | 2 | |
| -4 | 23.1 | 675,900 | 9 | Grip Failure |
| -7 | 23.1 | 675,050 | 9 | Grip Failure |
| -6 | 48.5 | 10,350 | 3 & 6 | |
| -8 | 48.5 | 10,870 | 6 | |
| -1 | 48.5 | 13,330 | 3 & 6 | |

(a) See failure mode description.

TABLE A-40. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** MVF6DA22
**Fastener System:** ST5300-CBS-12 Sleeve, HL11 Pin, HL97 Collar
**Interference Fit:** 0.018 Inch Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, 6AL-4V Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| MVF6DA22-1 | 40 | 20,910 | 3 & 6 | |
| -2 | 50 | 3,560 | 3 | |
| -3 | 25 | 491,550 | 3 | |
| -4 | 35 | 53,260 | 3 & 6 | |
| -5 | 20 | 396,730 | 9 | Grip Failure |
| -6 | 30 | 139,110 | 6 | |
| -7 | 20 | 922,220 | 6 | |
| -8 | 15 | 1,070,080 | 9 | Grip Failure |
| -9 | 30 | 84,550 | 6 | |
| -10 | 20 | 924,740 | 6 | |
| -11 | 40 | 18,380 | 3 & 6 | |
| -12 | 15 | 2,100,970 | 4 | |

(a) See failure mode description.

TABLE A-41. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** MVF6DA23
**Fastener System:** ST5300-CBC-12 Sleeve, HL11 Pin, HL97 Collar
**Interference Fit:** 0.018 Inch Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, 6AL-4V Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = - 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MVF6DA23-4 | 30 | 34,210 | 5 | |
| -1 | 40 | 19,530 | 3 & 6 | |
| -9 | 50 | 780 | 3 & 6 | |
| -2 | 20 | 208,680 | 5 | |
| -5 | 35 | 30,190 | 5 | |
| -3 | 25 | 112,990 | 8 | |
| -6 | 15 | 499,780 | 4 | |

(a) See failure mode description.

TABLE A-42. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MVF6DA25 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL11 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, 6AL-4V Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| MVF6DA25-1 | 23.1 | 1,357,000 | 4 | |
| -3 | 23.1 | 156,190 | 3 | |
| -12 | 34.6 | 115,880 | 6 | |
| -6 | 34.6 | 97,280 | 1 | |
| -7 | 48.5 | 2,750 | 1 | |
| -4 | 48.5 | 14,290 | 6 | |
| | | R = - 0.25 | | |
| MVF6DA25-11 | 17.9 | 328,130 | 6 | |
| -8 | 17.9 | 495,920 | 6 | |
| -9 | 26.8 | 136,250 | 1 & 2 | |
| -2 | 26.8 | 110,190 | 4 | |
| -5 | 37.6 | 39,020 | 5 | |
| -10 | 37.6 | 45,990 | 5 | |

(a) See failure mode description.

TABLE A-43. 3/8 INCH SPLIT SLEEVE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** MDF6DT31
**Fastener System:** ST5300-CBC-12 Sleeve, HL645 Pin, HL97 Collar
**Interference Fit:** 0.018 Inch Cold Work, 0.012 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, PH13-8Mo Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DT31-10 | 45 | 3,776,530 | 3 | |
| -7 | 50 | 500,750 | 6 | |
| -6 | 60 | 101,830 | 6 | |
| -5 | 80 | 20,920 | 6 | |
| -3 | 55 | 259,210 | 6 | |
| -4 | 80 | 23,000 | 6 | |
| -2 | 60 | 94,120 | 4 | |
| -1 | 70 | 40,780 | 6 | |

(a) See failure mode description.

TABLE A-44. 3/8 INCH SPLIT SLEEVE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MVF6DT35 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL11 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, 6AL-4V Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.6 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[(a)] | Remarks |
|---|---|---|---|---|
| MVF6DT35-1 | 80 | 22,880 | 3 & 7 | |
| -3 | 80 | 30,300 | 6 | |
| -4 | 65 | 40,420 | 6 | |
| -5 | 65 | 54,290 | 6 | |
| -6 | 55 | 183,580 | 3 | |
| -2 | 55 | 122,520 | 2 | |

(a) See failure mode description.

TABLE A-45. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

**Specimen Designation:** MDP6DA43
**Fastener System:** ST5300-CBC-12 Sleeve, HL644 Protruding Head Pin, HL97 Collar
**Interference Fit:** 0.018 Cold Work, 0.002 Inch Pin Interference
**Fastener Material:** A-286 Sleeve, PH13-8Mo Pin, A-286 Collar
**Stress Ratio, $S_{min}/S_{max}$:** R = + 0.25 or - 0.25
**Thickness to Diameter Ratio:** t/D = 1.7

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| MDP6DA43-5 | 23.1 | 277,130 | 9 | |
| -3 | 23.1 | 845,470 | 9 | Grip Failure |
| -7 | 34.6 | 97,970 | 4 | |
| -2 | 48.5 | 11,320 | 6 | |
| -10 | 48.5 | 9,080 | 6 | |
| | | R = - 0.25 | | |
| MDP6DA43-8 | 17.9 | 306,470 | 6 & 8 | |
| -6 | 17.9 | 310,900 | 6 & 8 | |
| -4 | 26.8 | 119,660 | 6 | |
| -9 | 37.6 | 26,110 | 6 | |
| -1 | 37.6 | 16,820 | 4 | |

(a) See failure mode description.

TABLE A-46. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MDP6DA45 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL644 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, PH13-8Mo Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.25 or - 0.25 |
| **Thickness to Diameter Ratio:** | t/D = 0.5 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| | | R = + 0.25 | | |
| MDP6DA45-1 | 23.1 | 445,730 | 3 | |
| -2 | 23.1 | 3,197,050 | 3 | |
| -7 | 34.6 | 88,770 | 8 | |
| -3 | 34.6 | 168,530 | 6 | |
| -5 | 48.5 | 5,240 | 4 | |
| -4 | 48.5 | 20,380 | 6 | |
| | | R = - 0.25 | | |
| MDP6DA45-8 | 17.9 | 1,349,260 | 5 | |
| -6 | 17.9 | 715,050 | 9 | Grip Failure |
| -10 | 26.8 | 141,880 | 3 | |
| -11 | 26.8 | 129,060 | 3 | |
| -9 | 37.6 | 39,780 | 8 | |
| -12 | 37.6 | 47,880 | 1 | |

(a) See failure mode description.

TABLE A-47. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MDF6DA48 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL645 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, PH13-8Mo Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + .1 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DA48-2 | 48.5 | 7,330 | 6 | |
| -4 | 48.5 | 5,180 | 3 & 6 | |
| -3 | 23.1 | 162,020 | 5 | |
| -1 | 23.1 | 389,020 | 6 & 8 | |

**(a) See failure mode description.**

TABLE A-48. 3/8 INCH SPLIT SLEEVE, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MDF6DA49 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL645 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, PH13-8Mo Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = - 1.0 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DA49-2 | 16.3 | 265,520 | 2 & 8 | |
| -1 | 16.3 | 140,420 | 6 & 8 | |
| -3 | 29.7 | 25,450 | 8 | |
| -4 | 29.7 | 28,920 | 5 | |

(a) See failure mode description.

TABLE A-49. 3/8 INCH SPLIT SLEEVE, 6AL-4V M.A. LOW-LOAD TRANSFER SPECIMENS

| | |
|---|---|
| **Specimen Designation:** | MDF6DT52 |
| **Fastener System:** | ST5300-CBC-12 Sleeve, HL645 Pin, HL97 Collar |
| **Interference Fit:** | 0.018 Inch Cold Work, 0.002 Inch Pin Interference |
| **Fastener Material:** | A-286 Sleeve, PH13-8Mo Pin, A-286 Collar |
| **Stress Ratio, $S_{min}/S_{max}$:** | R = + 0.1 |
| **Thickness to Diameter Ratio:** | t/D = 1.7 |

| Specimen Identification | Max Stress Gross Area, ksi | Cycles to Failure N.F. = No Failure | Mode of Failure[a] | Remarks |
|---|---|---|---|---|
| MDF6DT52-3 | 55 | 92,940 | 7 | |
| -2 | 55 | 129,800 | 4 & 7 | |
| -4 | 80 | 22,020 | 3 & 6 | |

(a) See failure mode description.

APPENDIX B

FATIGUE LIFE CURVES FOR PRIMARY VARIABLES

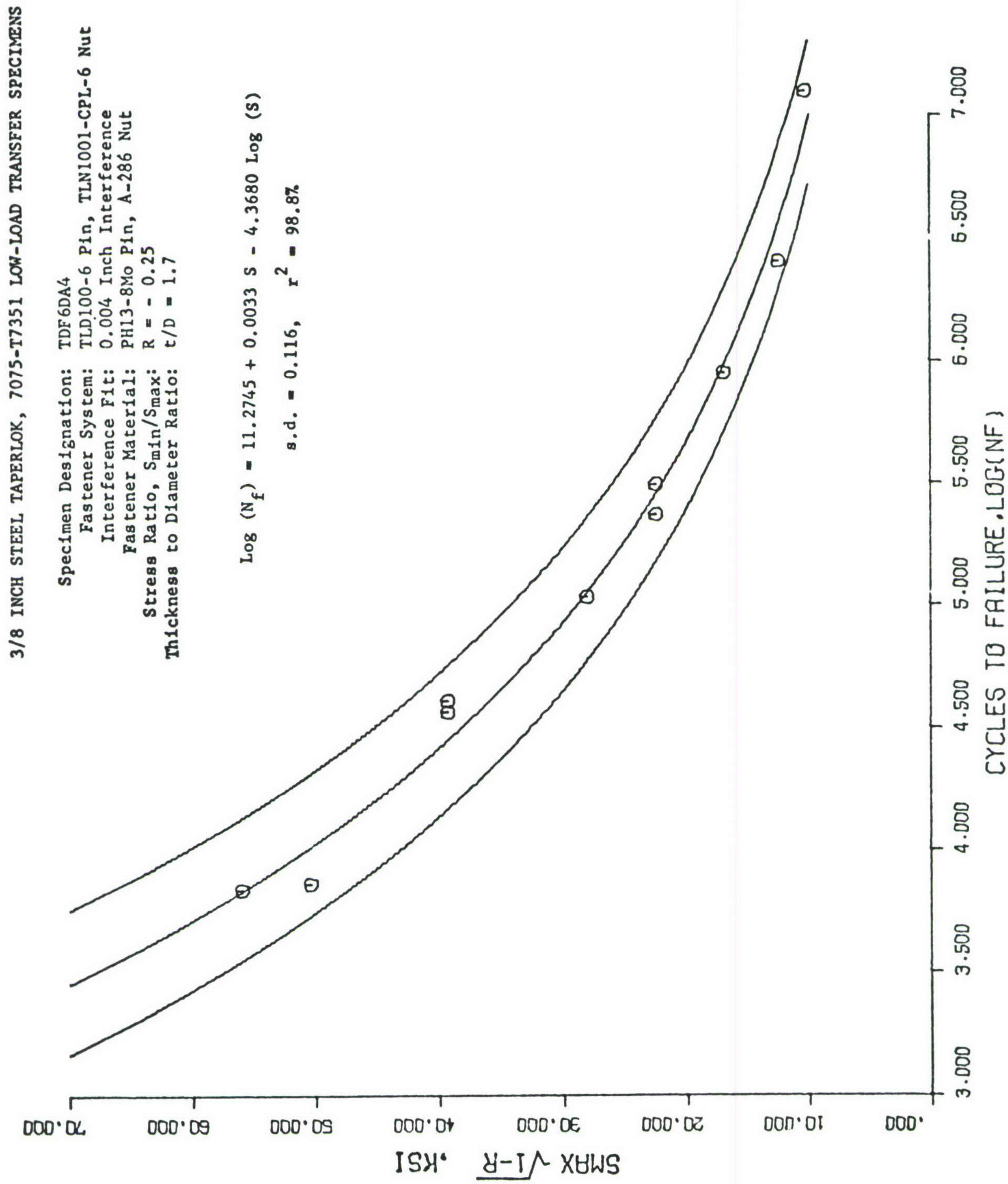



FIGURE B-1. FASTENER FATIGUE IMPROVEMENT DATA

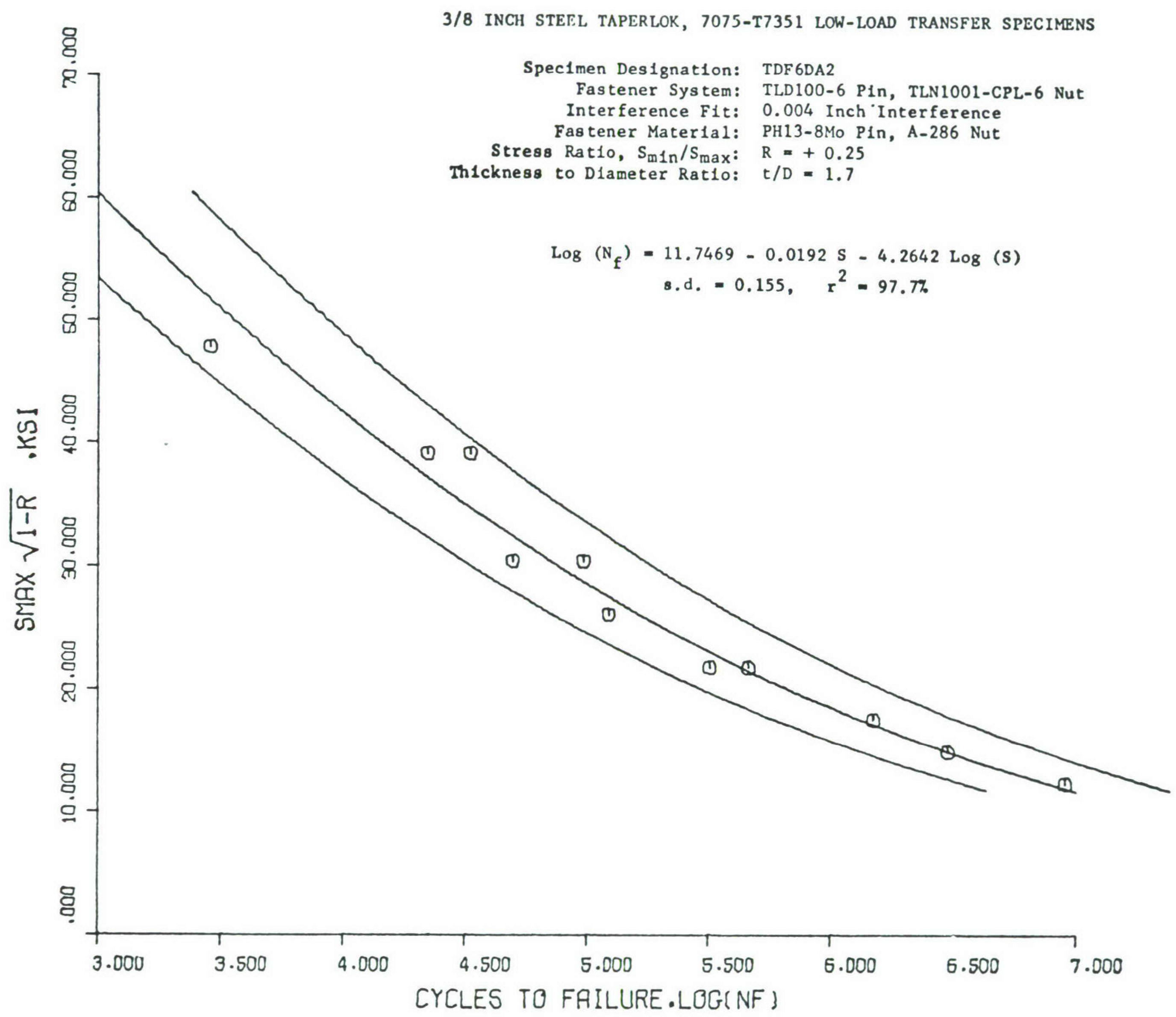



FIGURE B-2. FASTENER FATIGUE IMPROVEMENT DATA

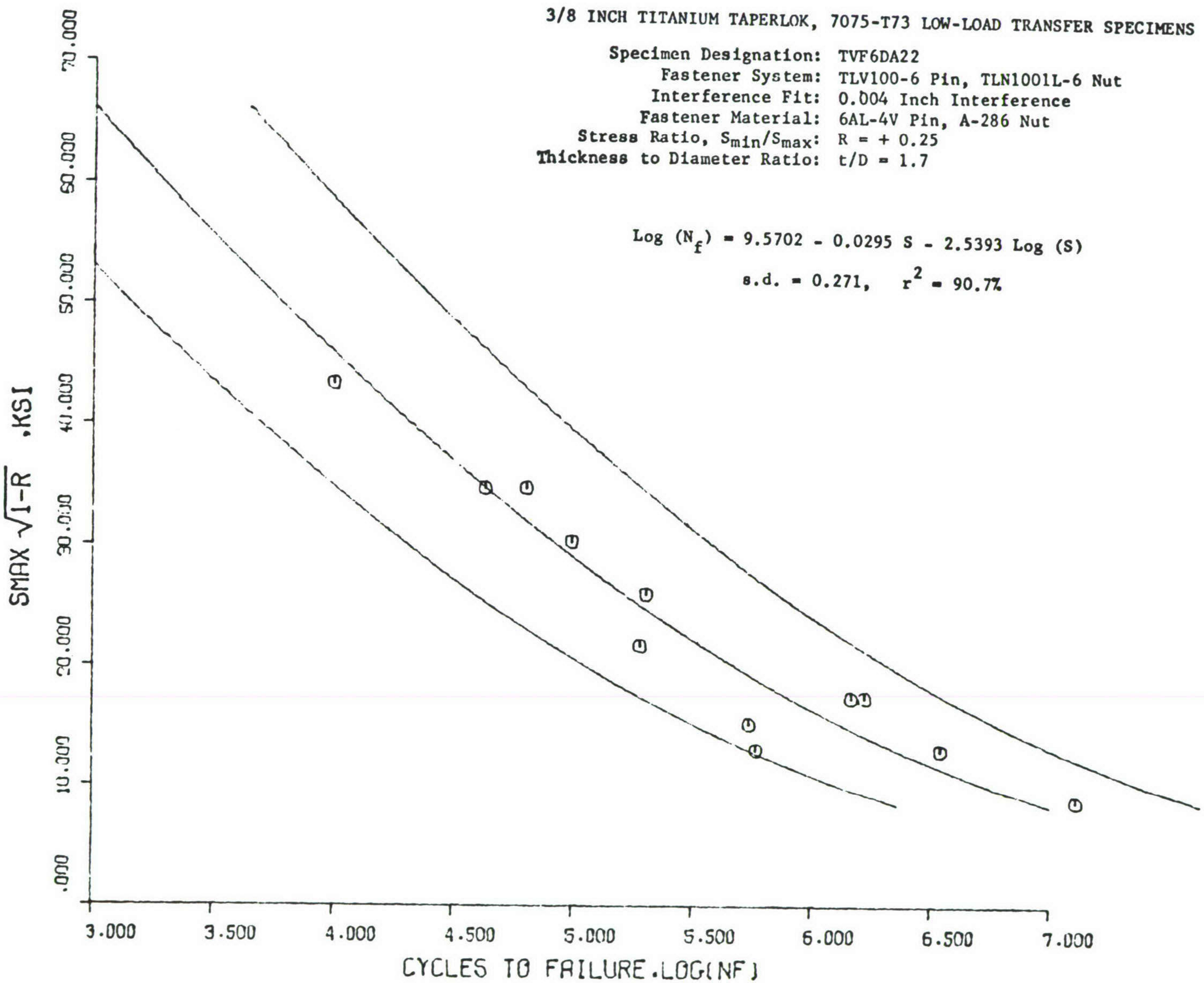



FIGURE B-3. FASTENER FATIGUE IMPROVEMENT DATA

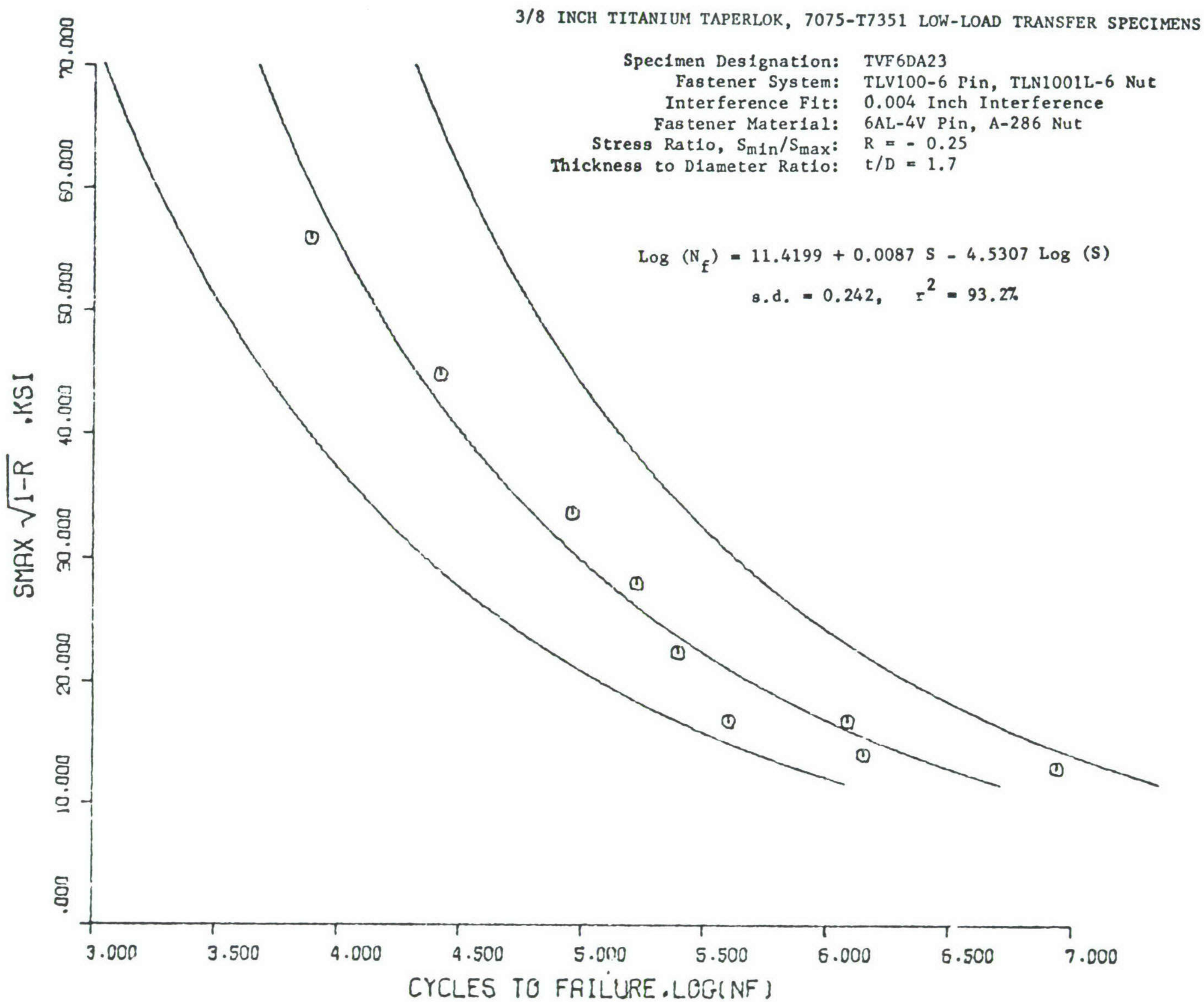



FIGURE B-4. FASTENER FATIGUE IMPROVEMENT DATA

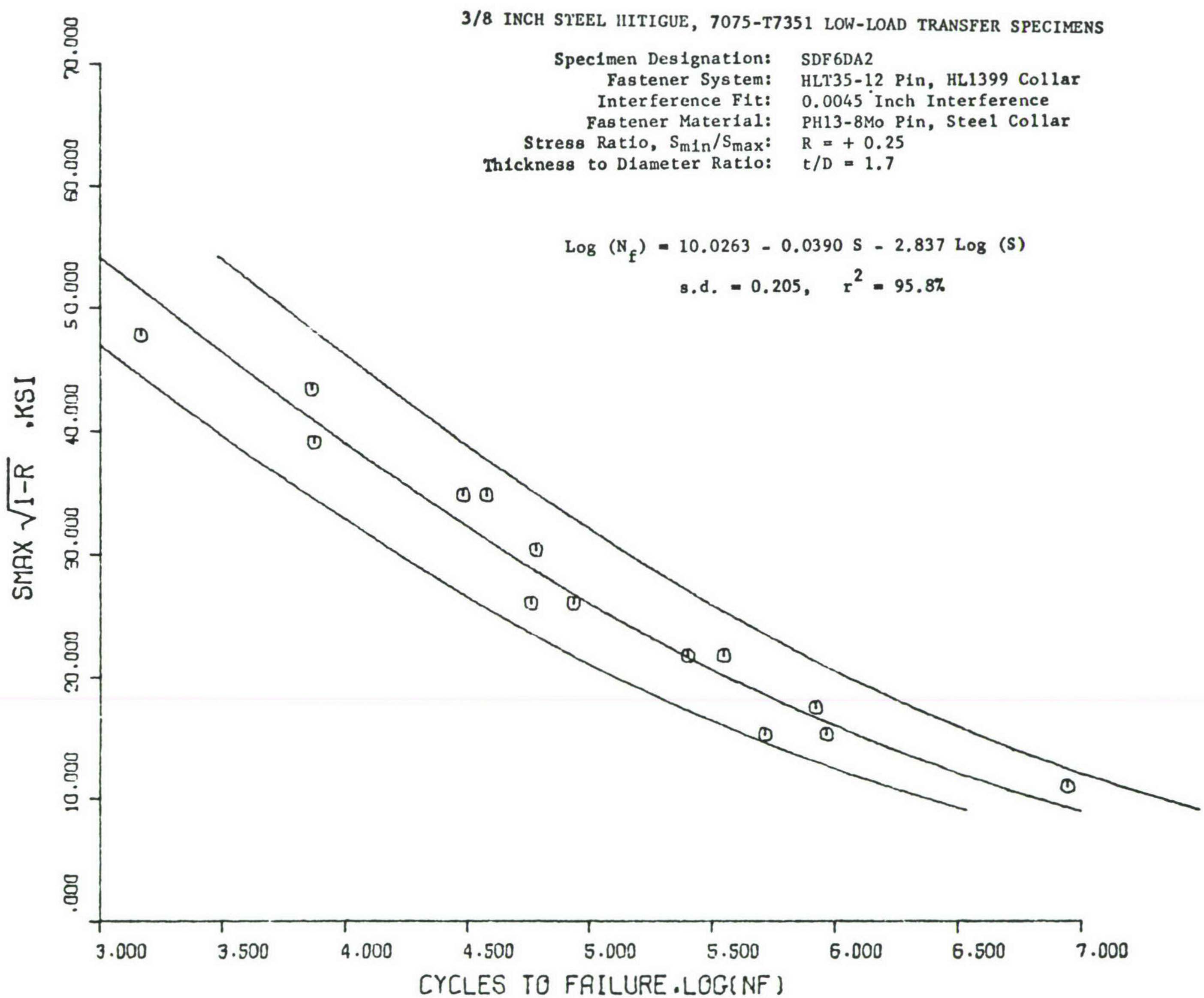



FIGURE B-5. FASTENER FATIGUE IMPROVEMENT DATA

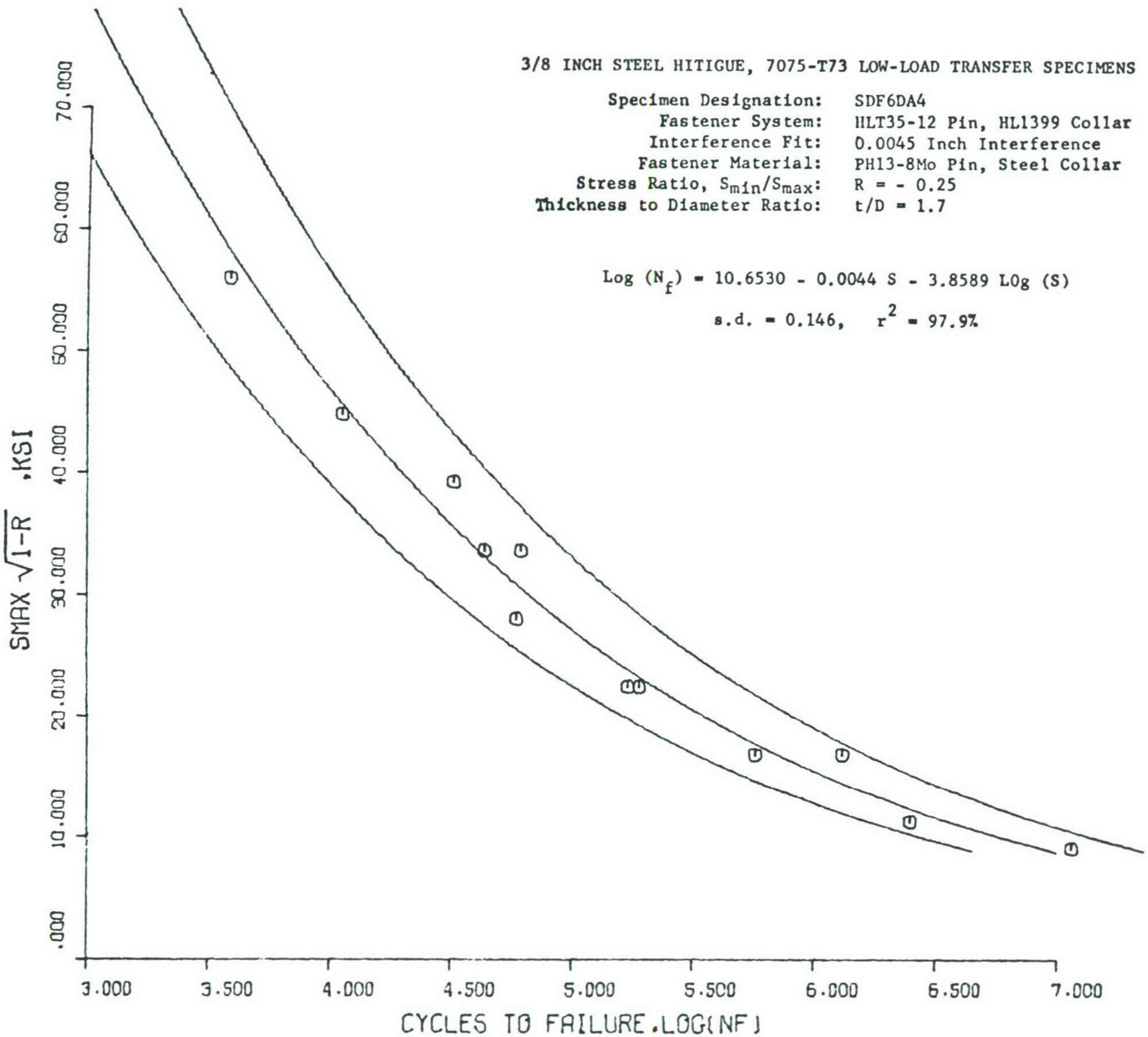



FIGURE B-6. FASTENER FATIGUE IMPROVEMENT DATA

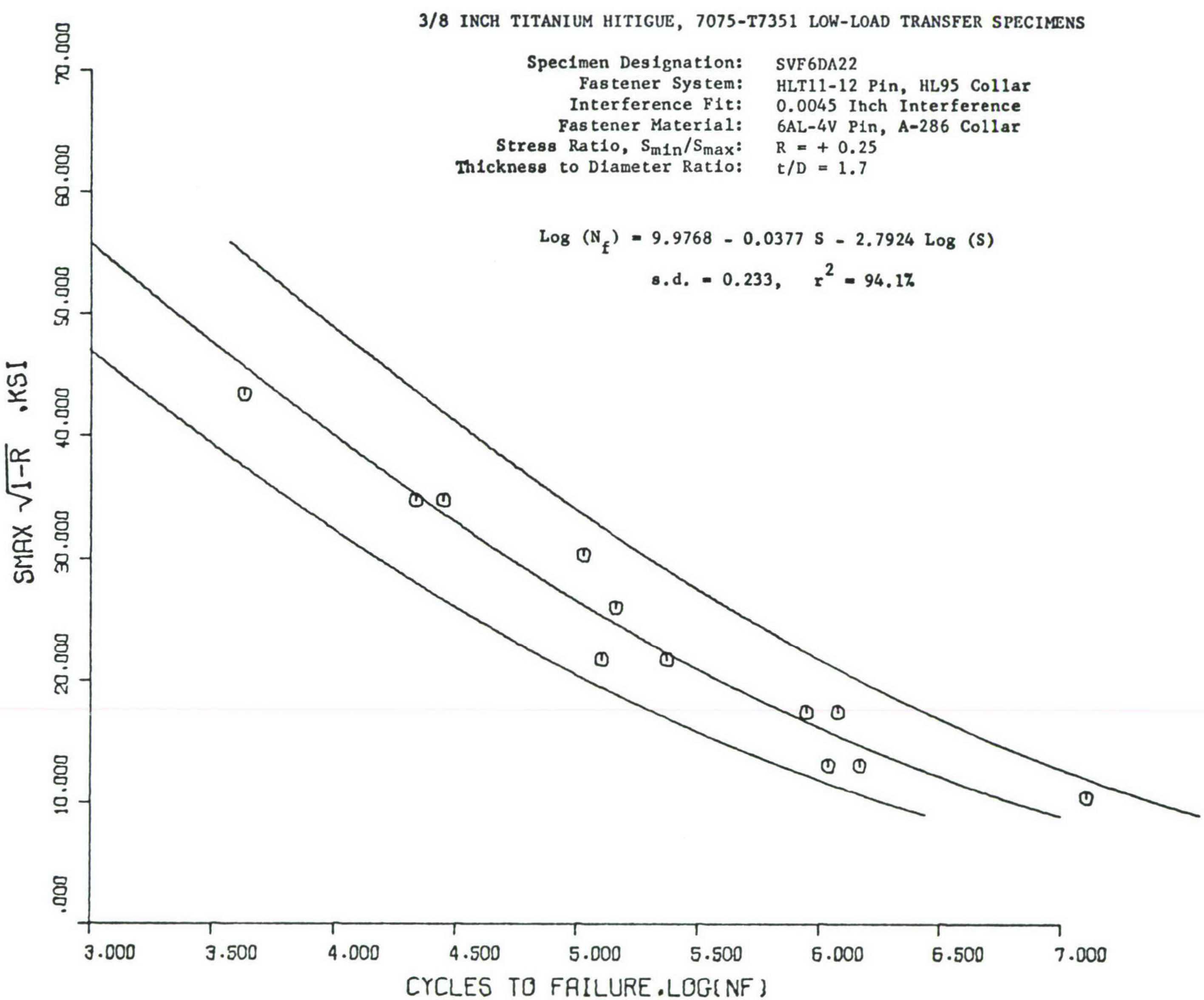



FIGURE B-7. FASTENER FATIGUE IMPROVEMENT DATA

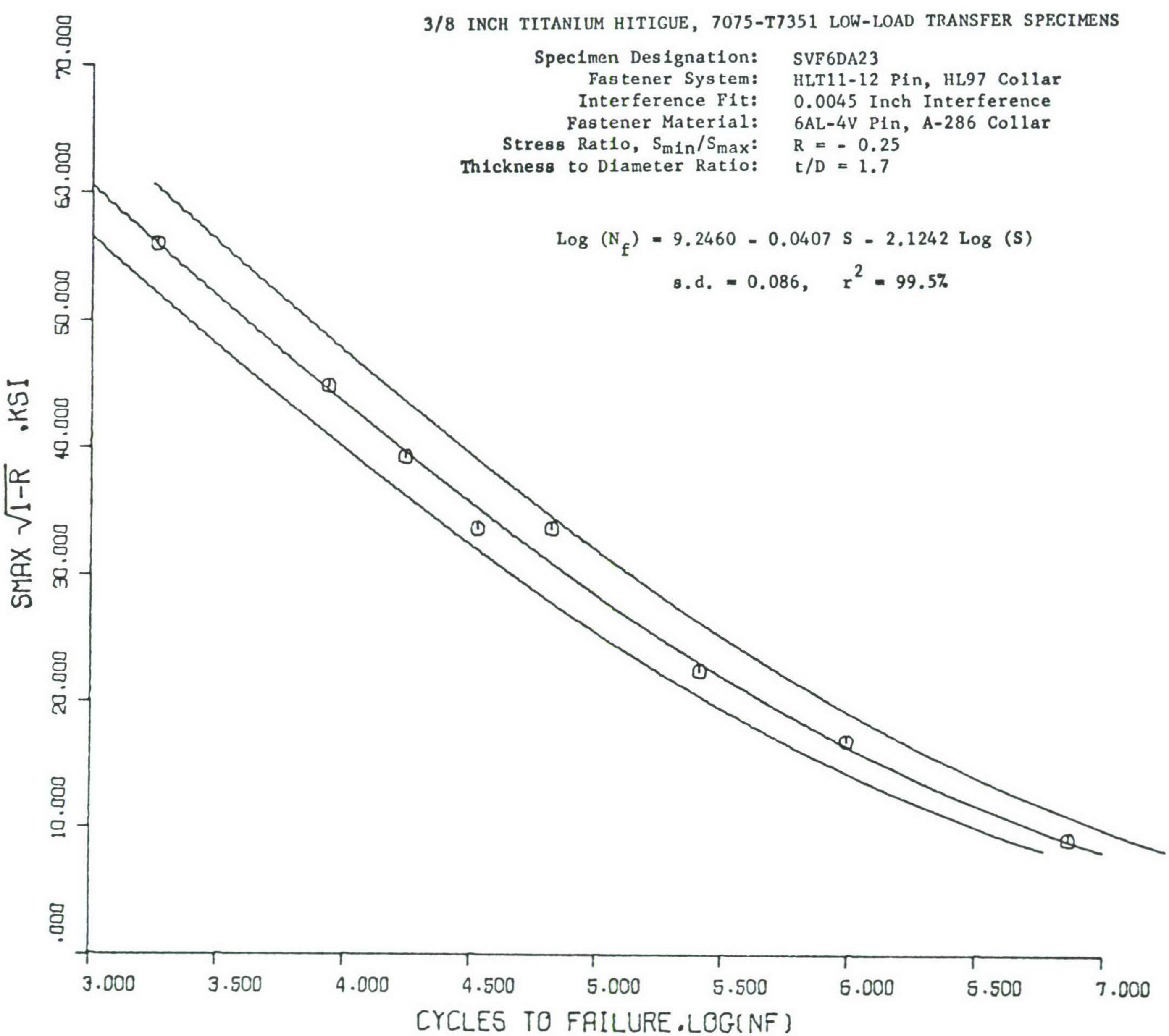



FIGURE B-8. FASTENER FATIGUE IMPROVEMENT DATA

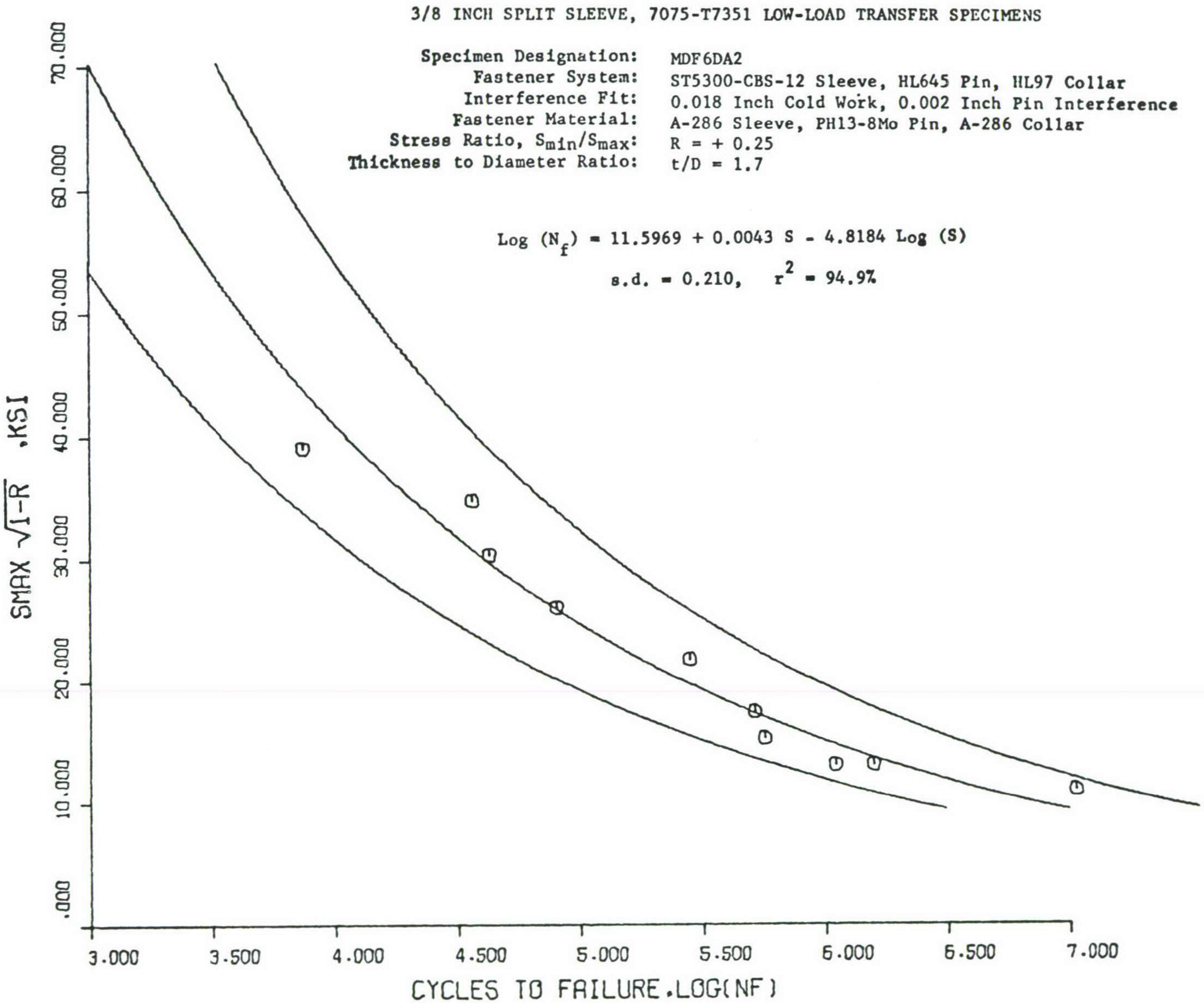



FIGURE B-9. FASTENER FATIGUE IMPROVEMENT DATA

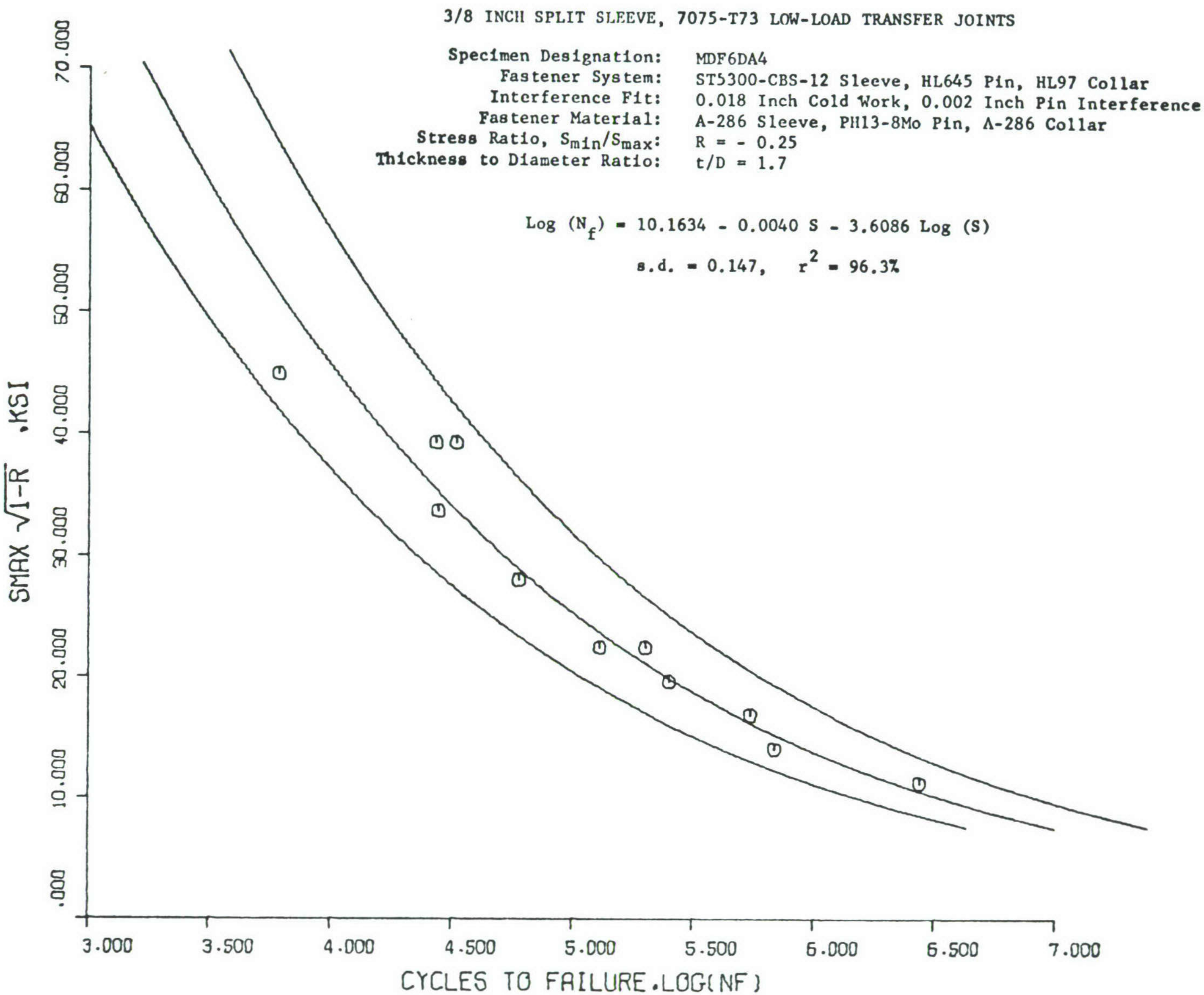



FIGURE B-10. FASTENER FATIGUE IMPROVEMENT DATA

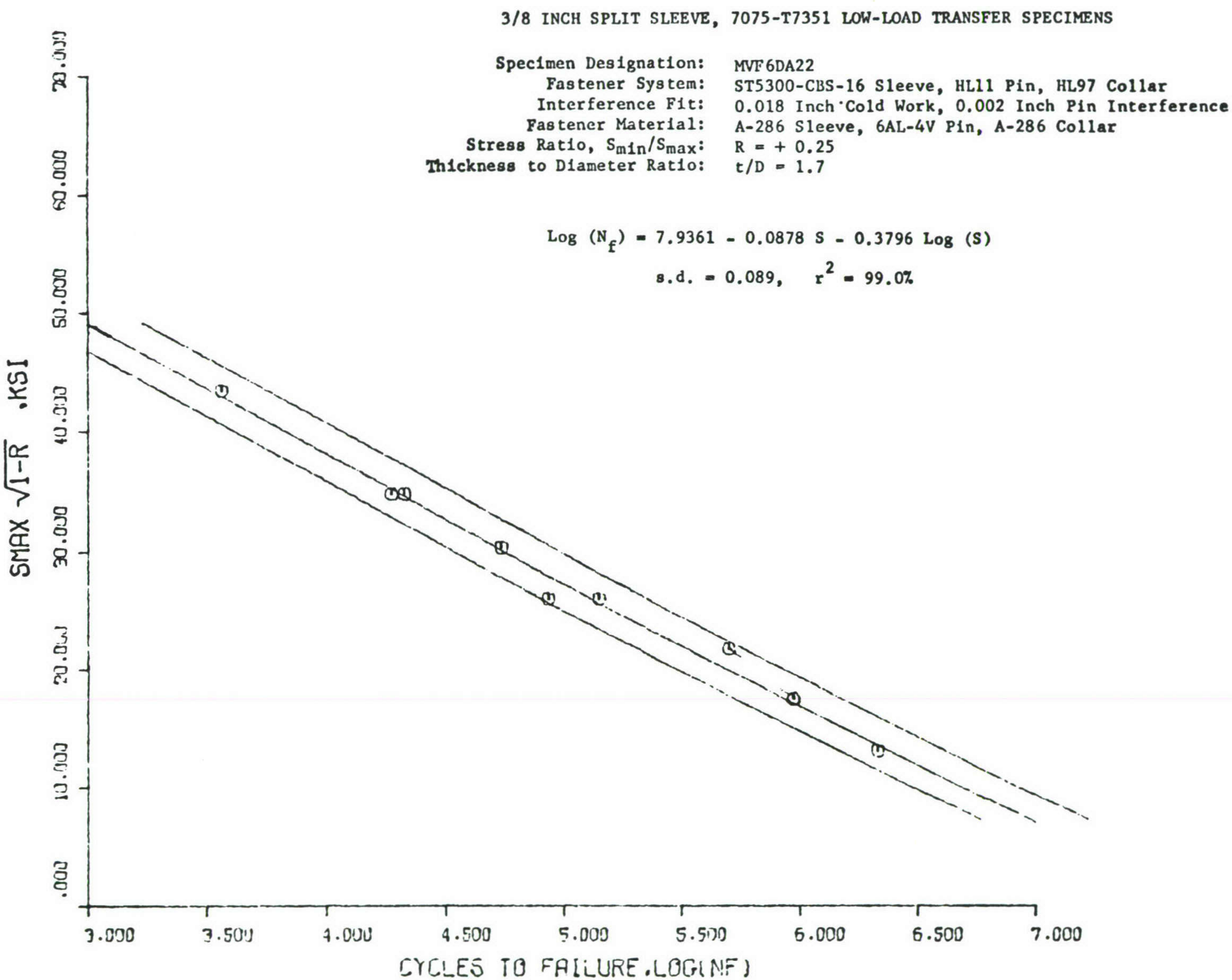



FIGURE B-11. FASTENER FATIGUE IMPROVEMENT DATA

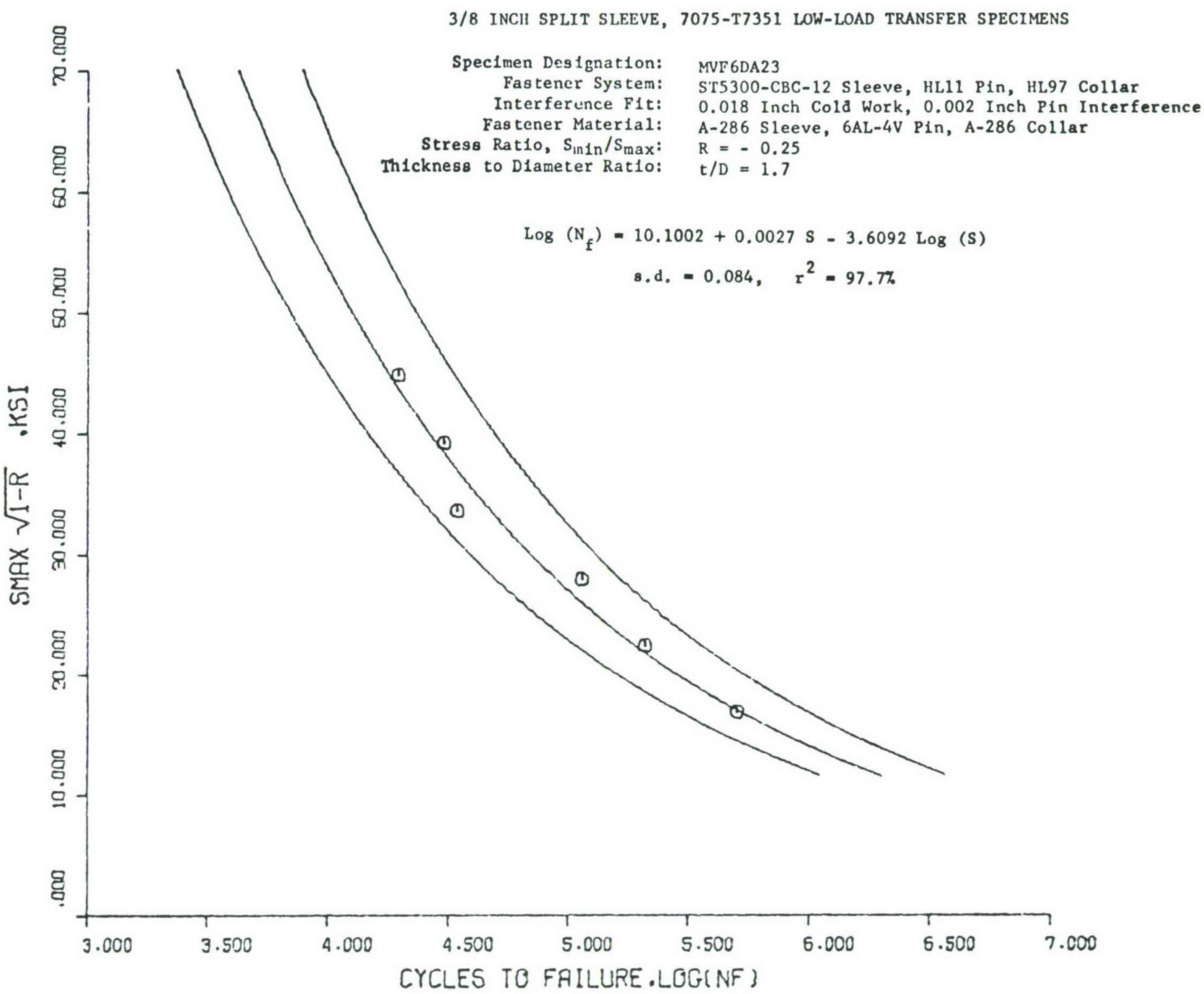



FIGURE B-12. FASTENER FATIGUE IMPROVEMENT DATA

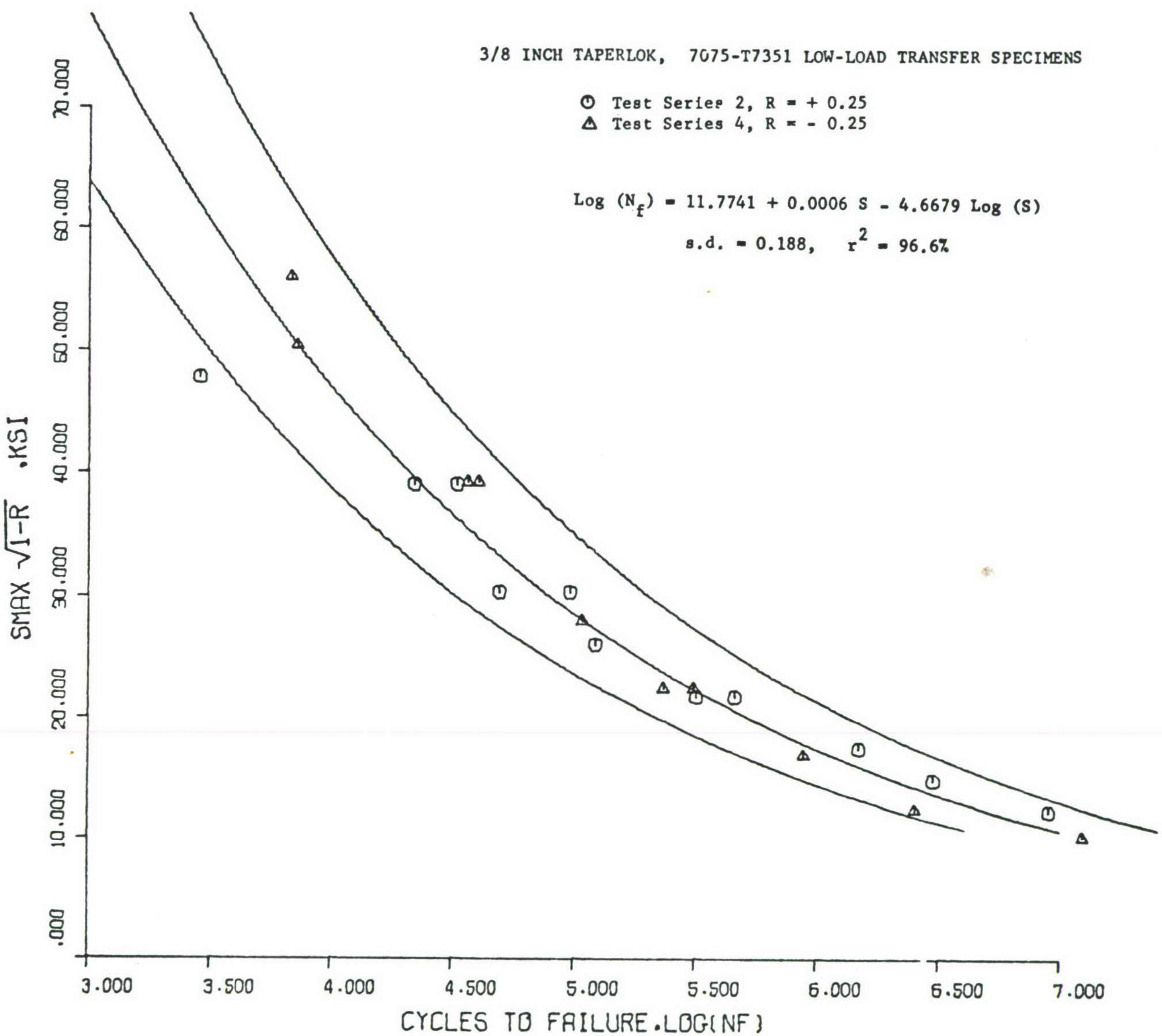



FIGURE B-13. FASTENER FATIGUE IMPROVEMENT DATA

3/8 INCH TITANIUM TAPERLOK, 7075-T7351 LOW-LOAD TRANSFER SPECIMENS

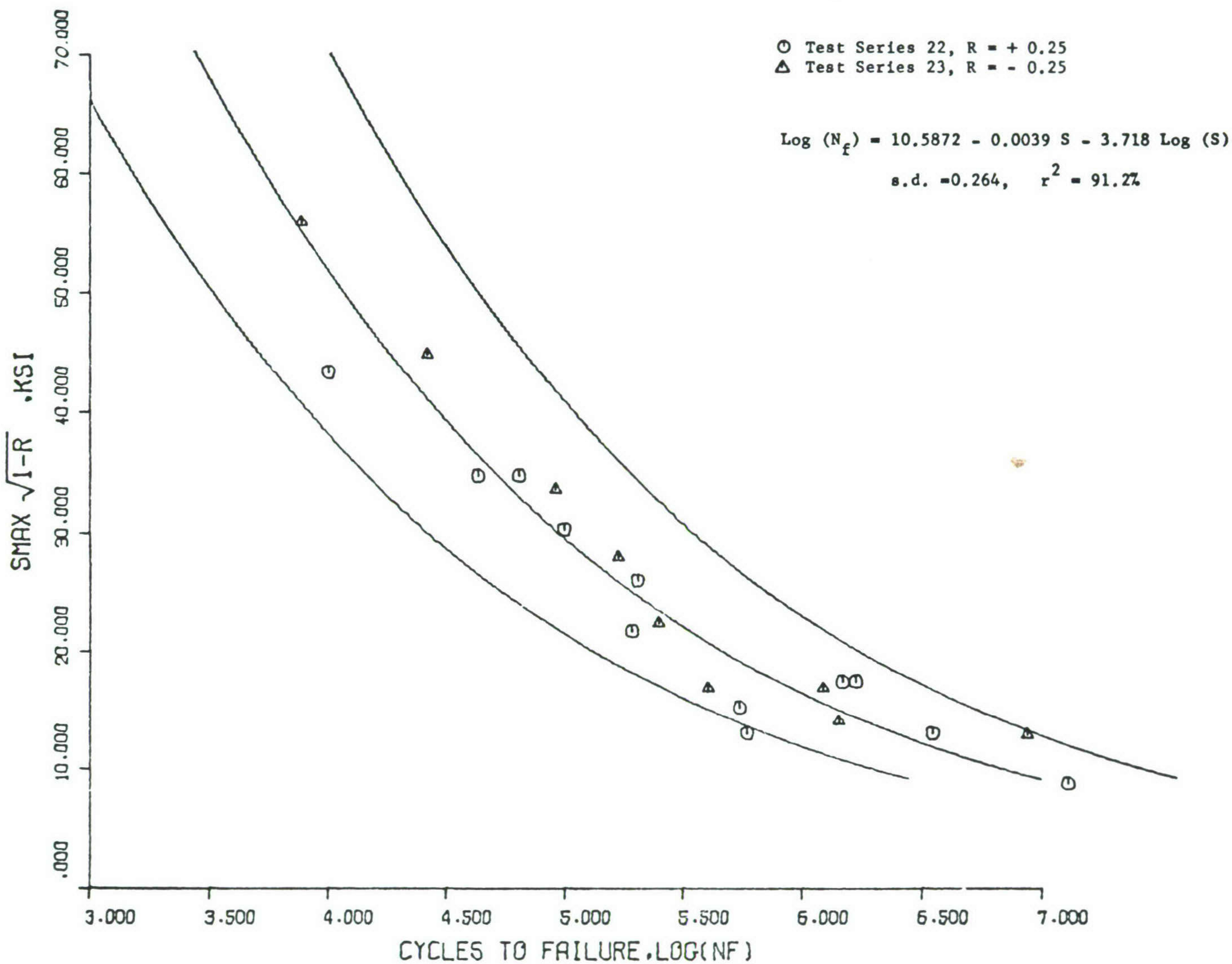



FIGURE B-14. FASTENER FATIGUE IMPROVEMENT DATA

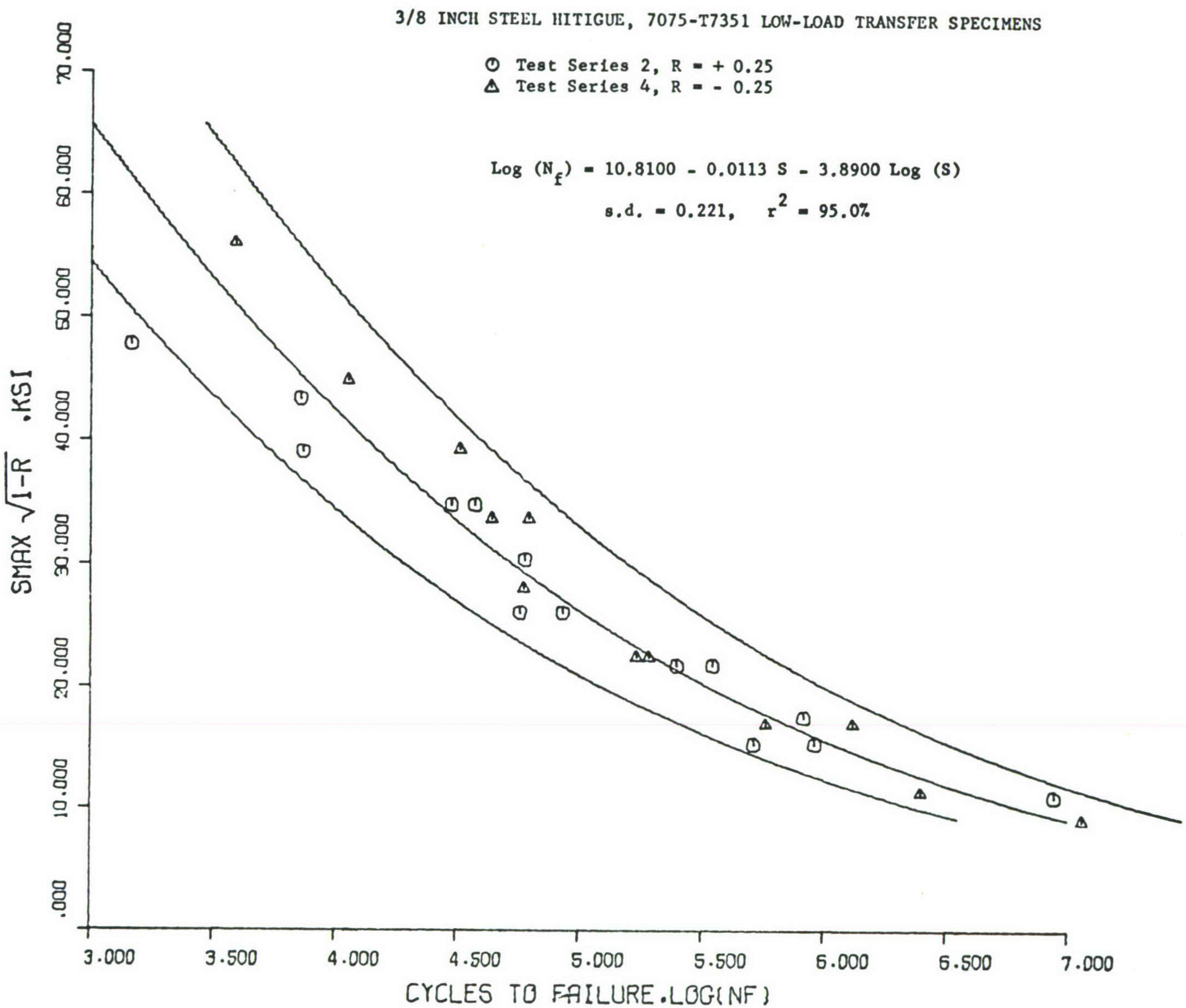



FIGURE B-15. FASTENER FATIGUE IMPROVEMENT DATA

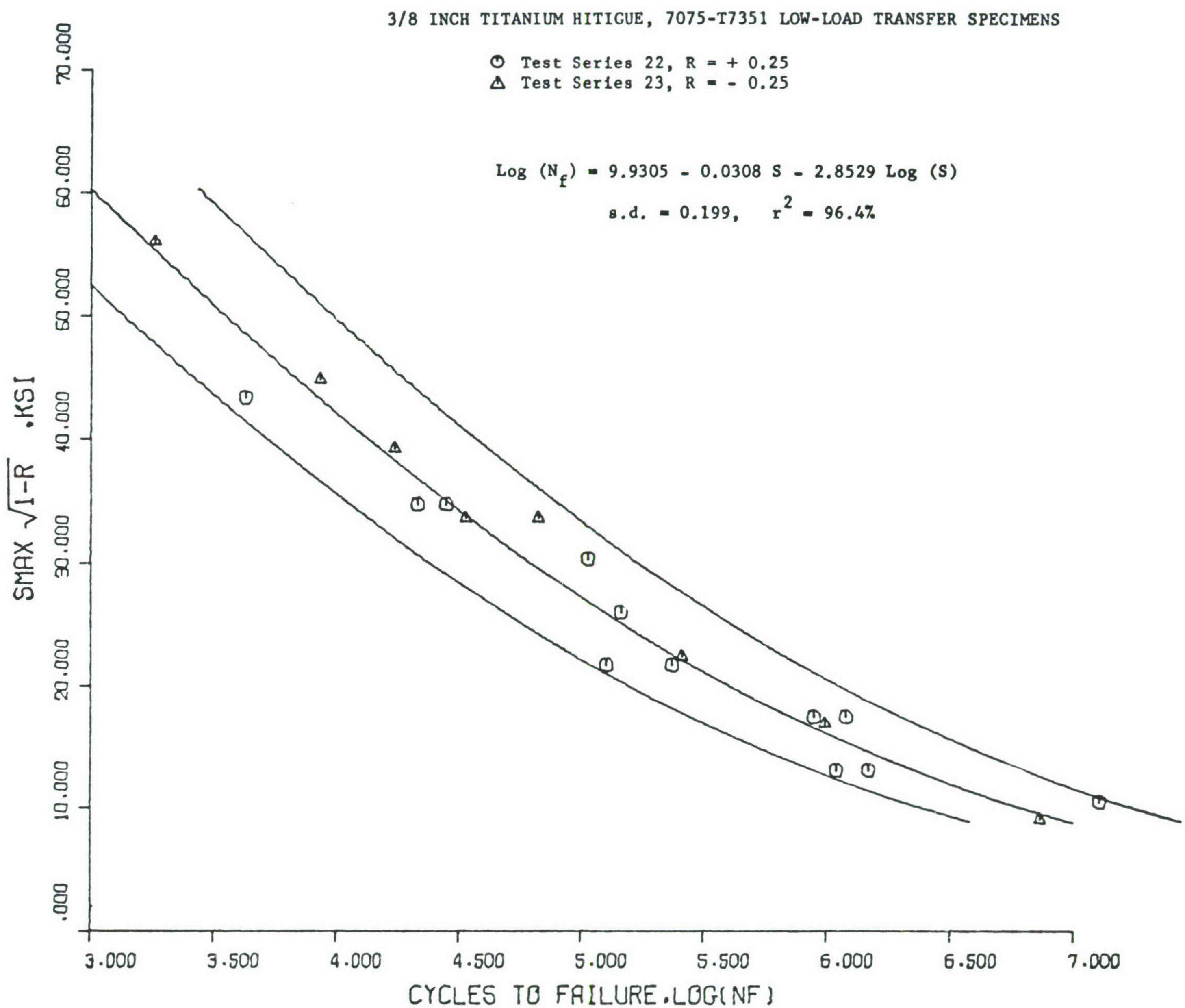



FIGURE B-16. FASTENER FATIGUE IMPROVEMENT DATA

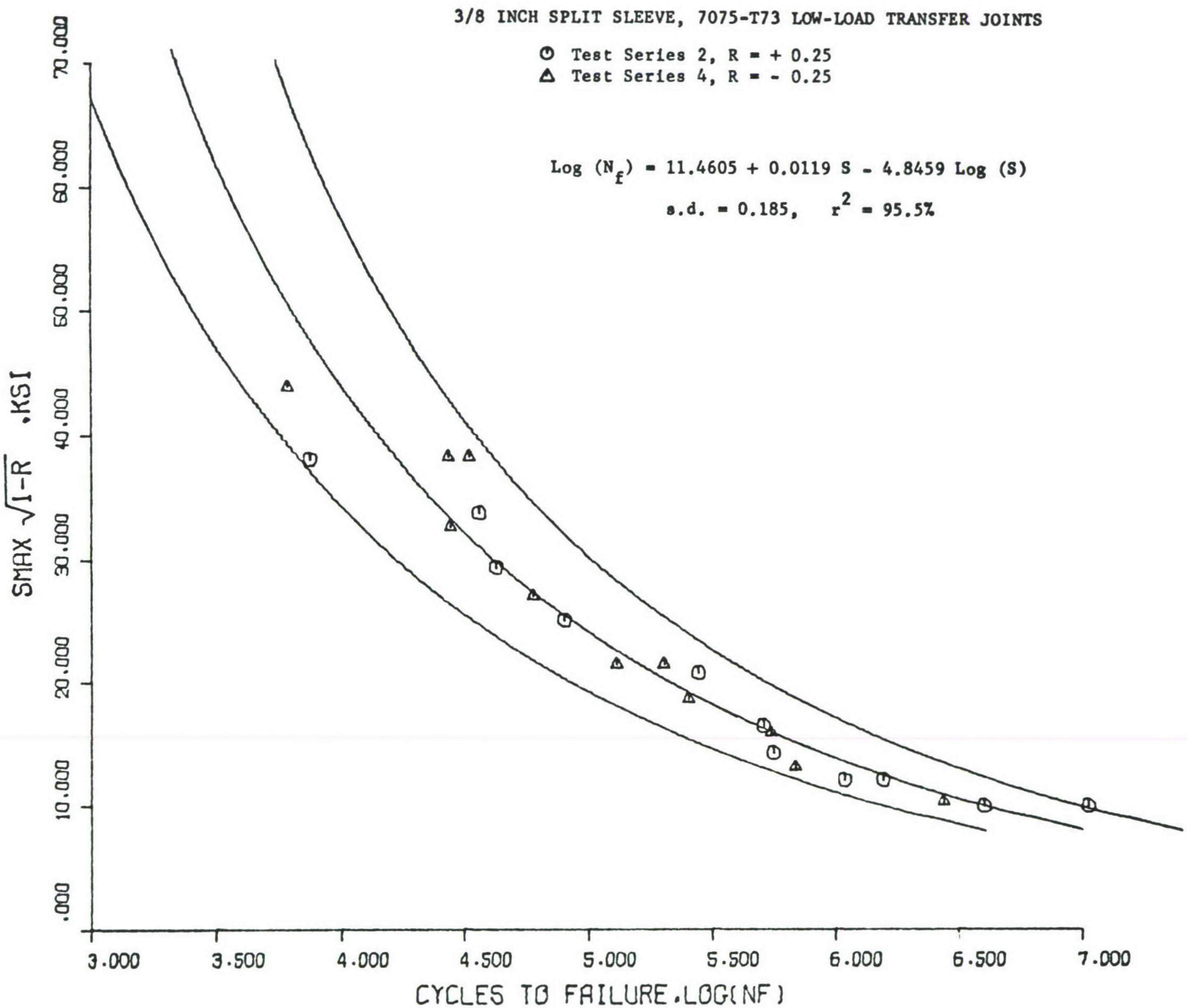



FIGURE B-17. FASTENER FATIGUE IMPROVEMENT DATA

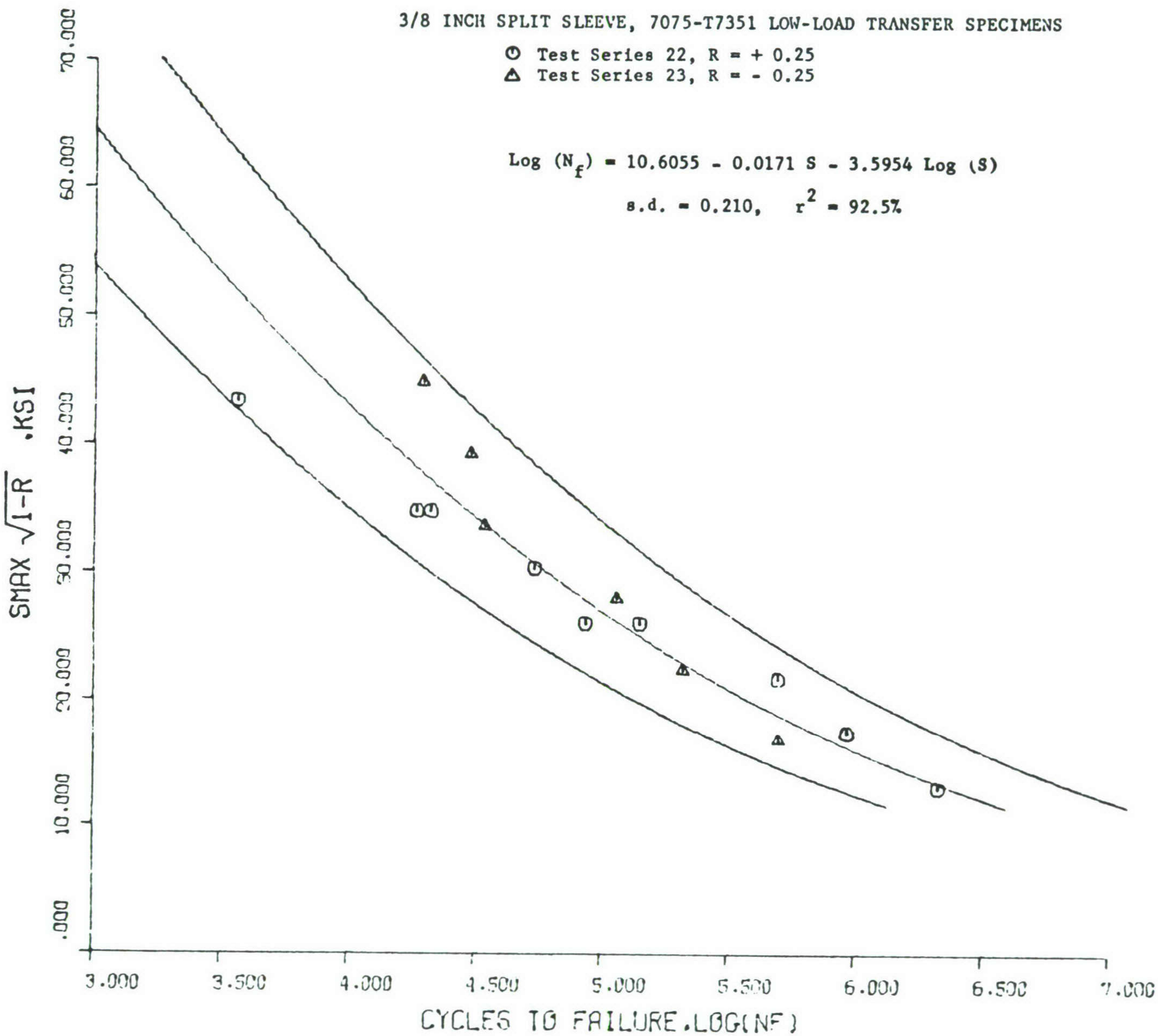



FIGURE B-18. FASTENER FATIGUE IMPROVEMENT DATA

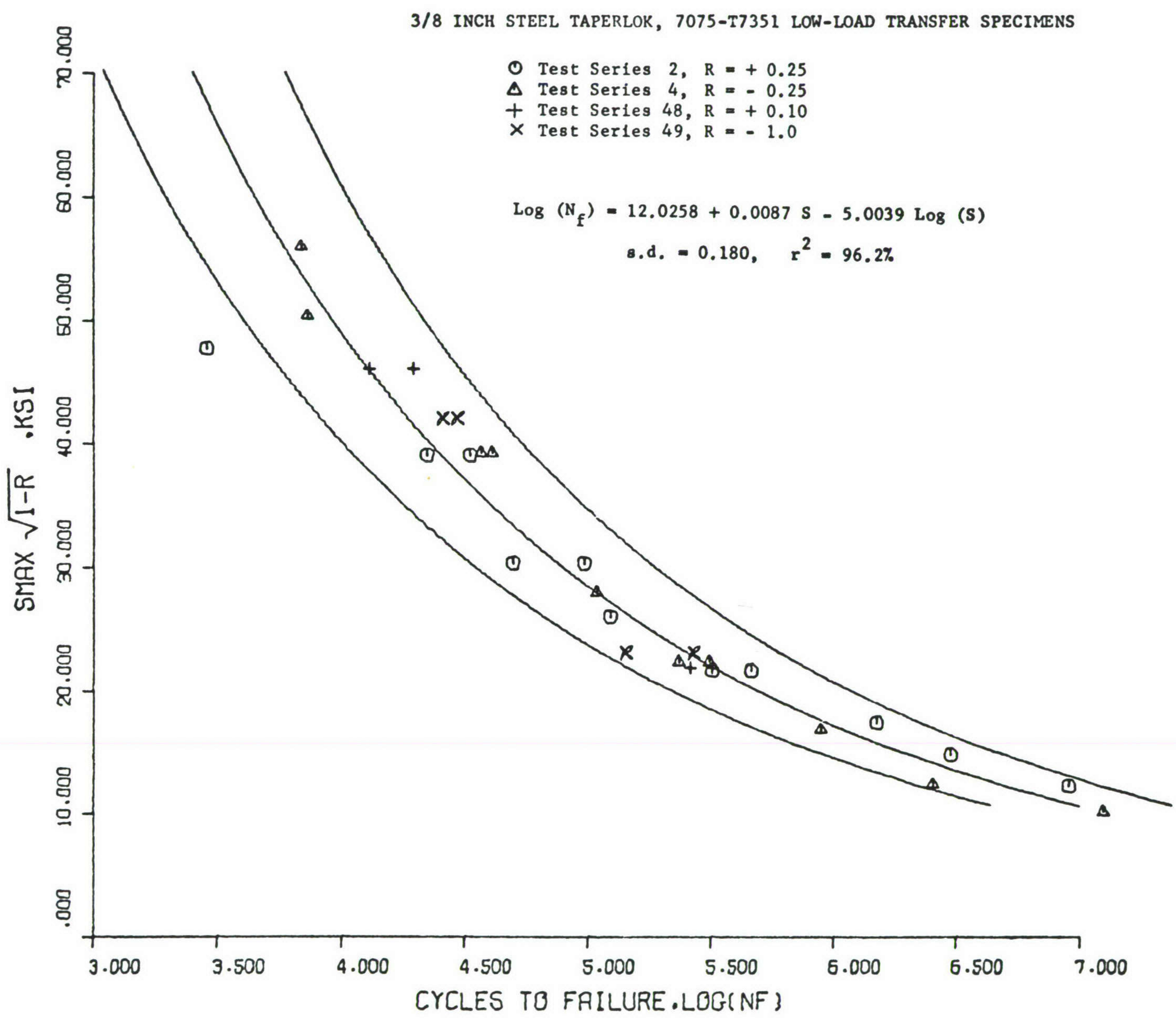



FIGURE B-19. FASTENER FATIGUE IMPROVEMENT DATA

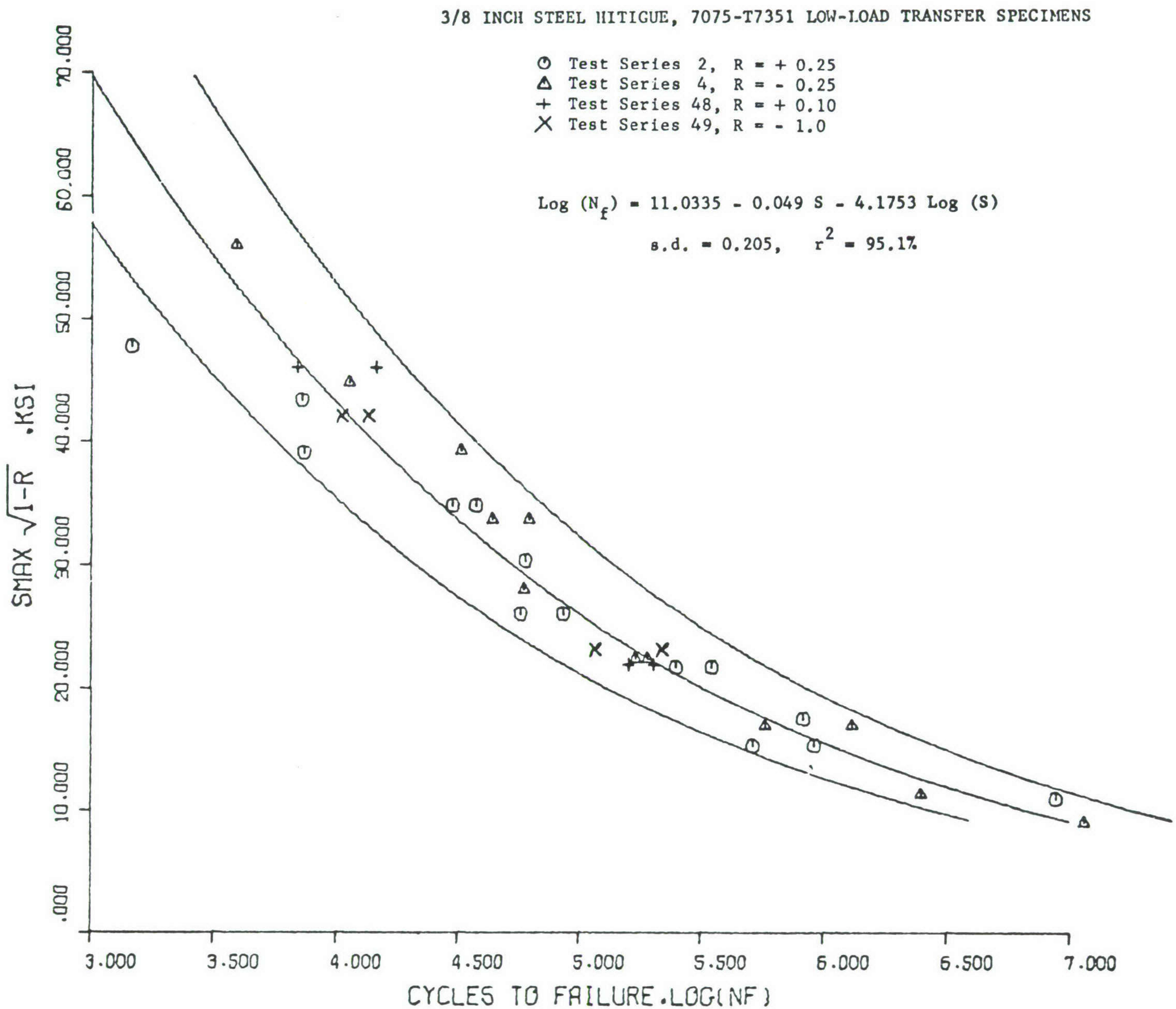



FIGURE B-20. FASTENER FATIGUE IMPROVEMENT DATA

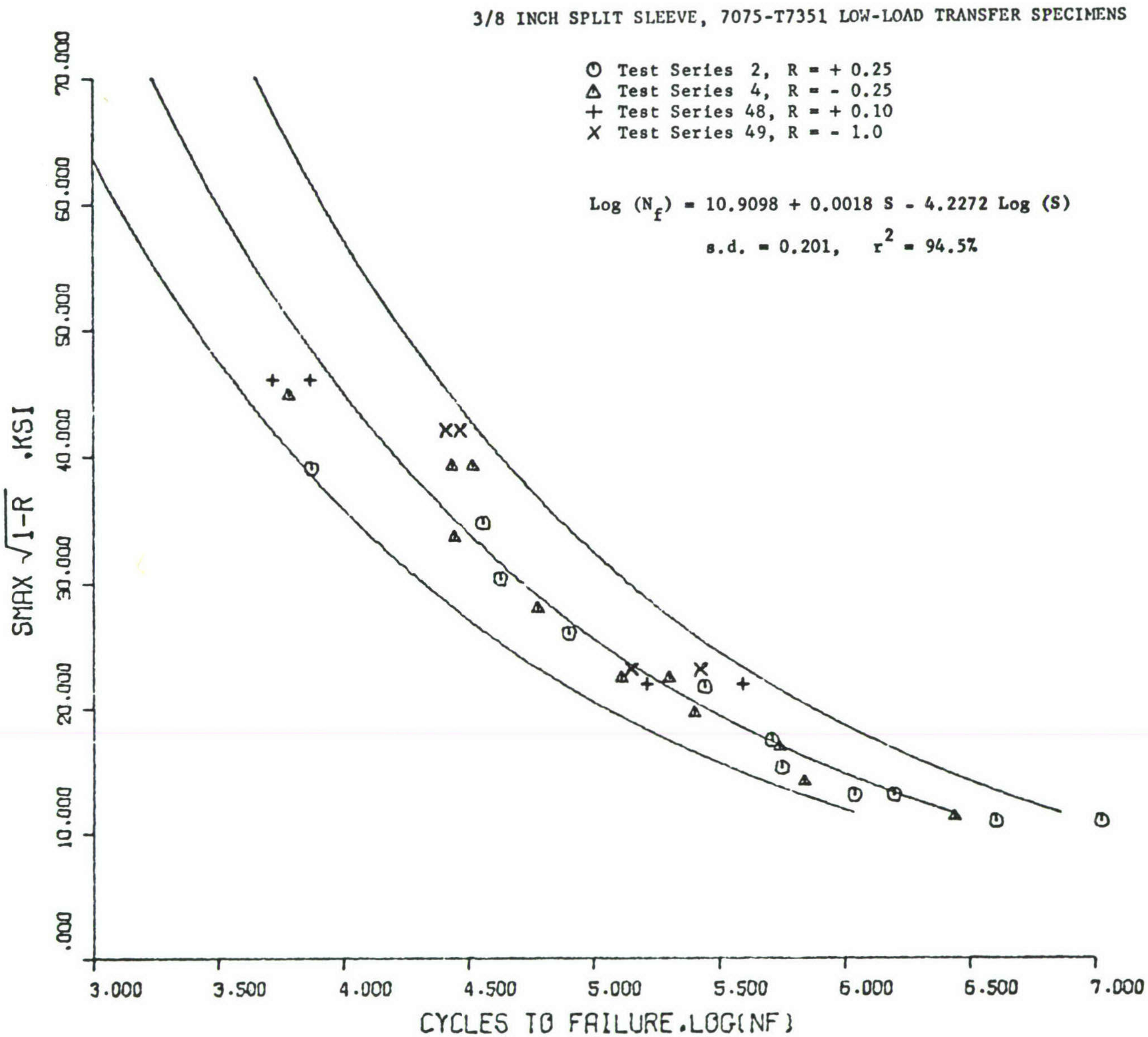



FIGURE B-21. FASTENER FATIGUE IMPROVEMENT DATA

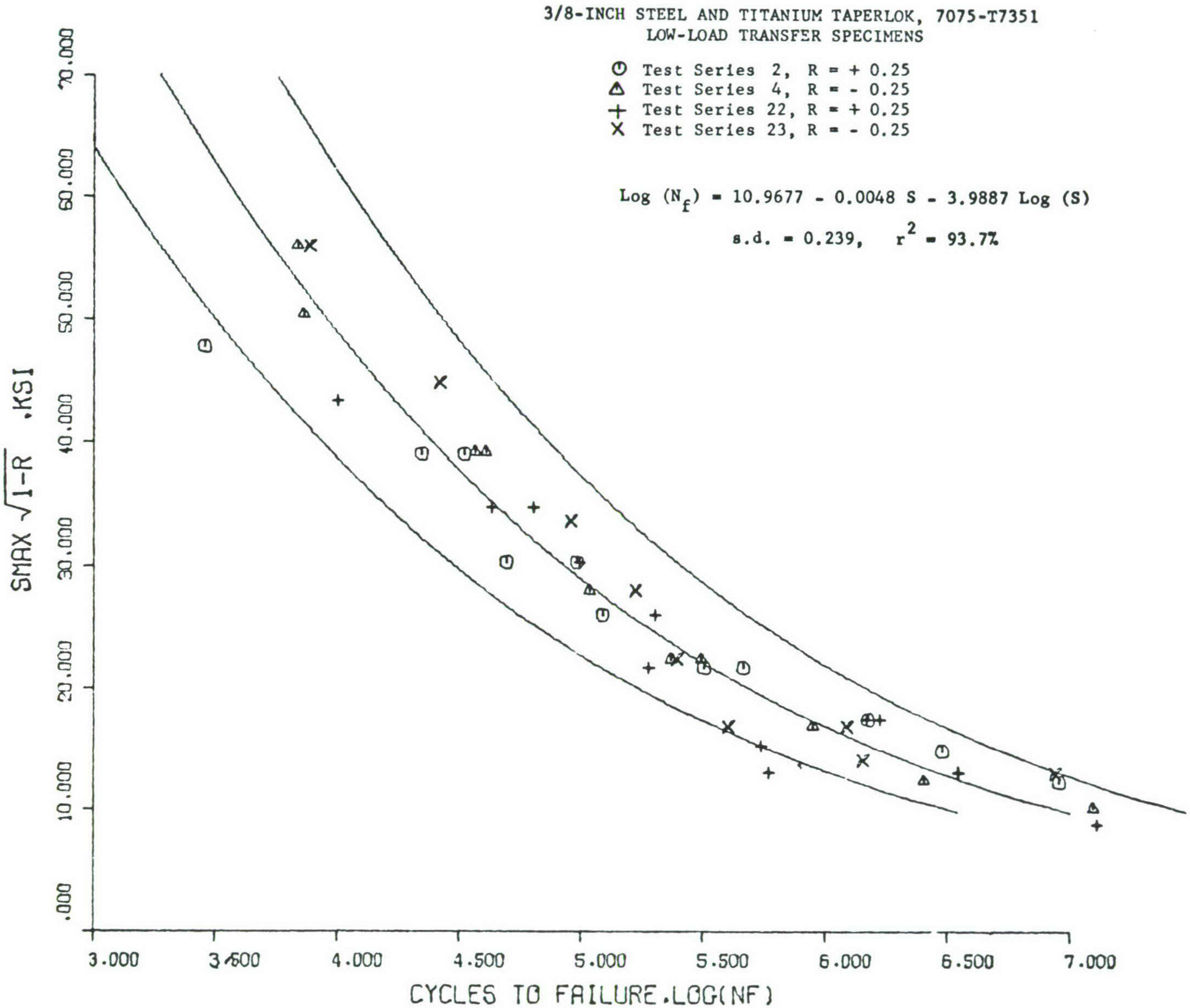



FIGURE B-22. FASTENER FATIGUE IMPROVEMENT DATA

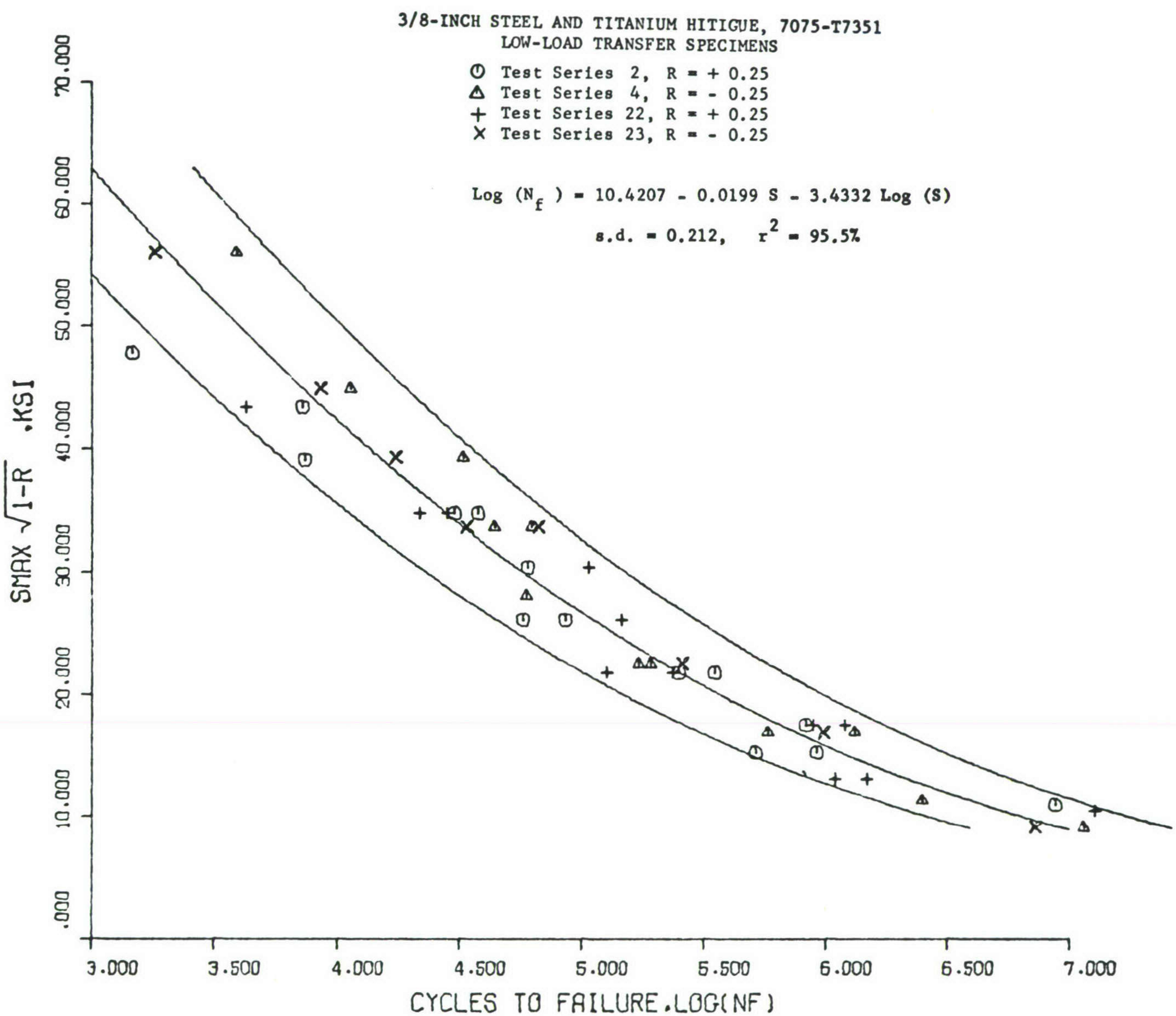



FIGURE B-23. FASTENER FATIGUE IMPROVEMENT DATA

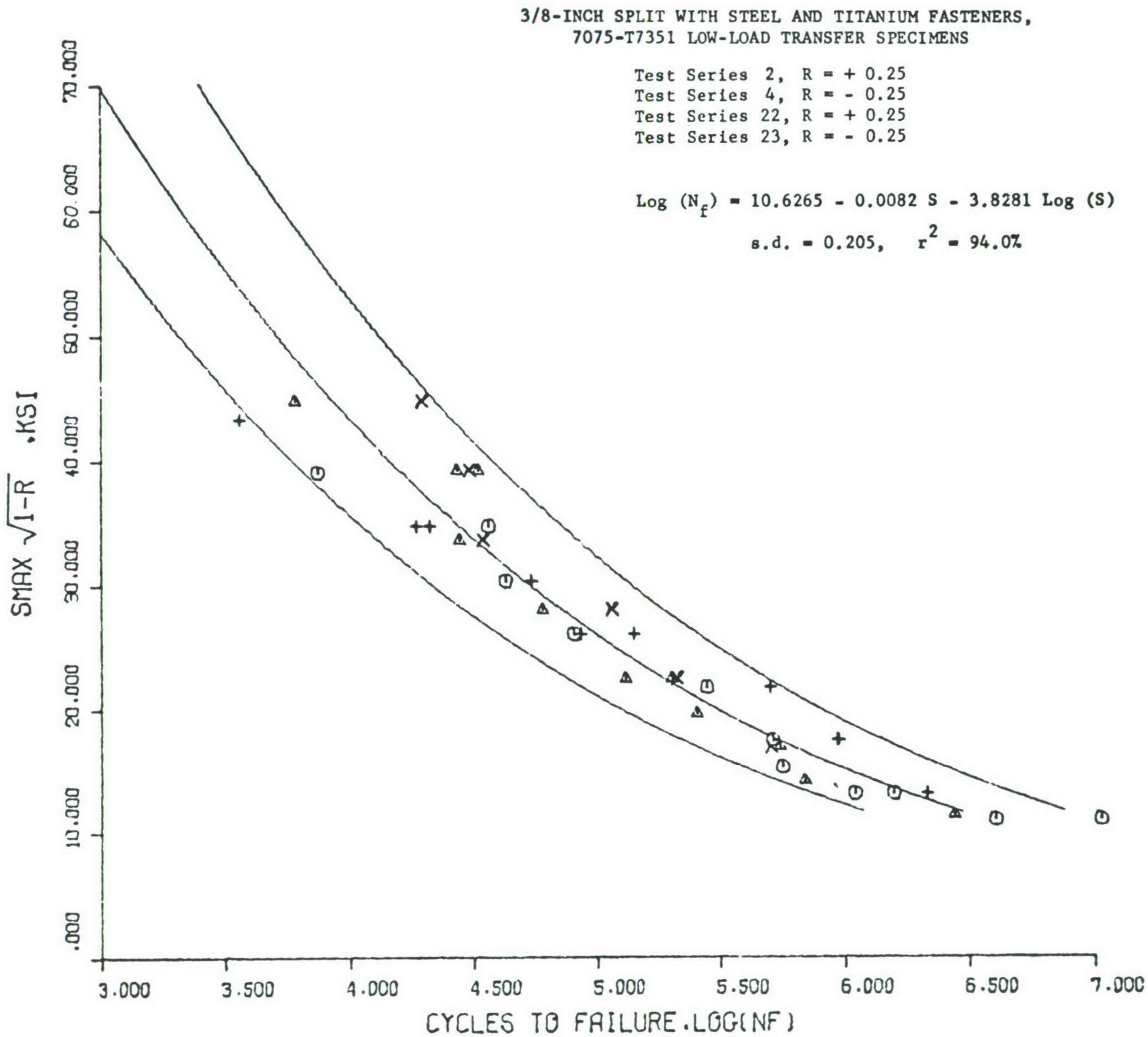



FIGURE B-24. FASTENER FATIGUE IMPROVEMENT DATA

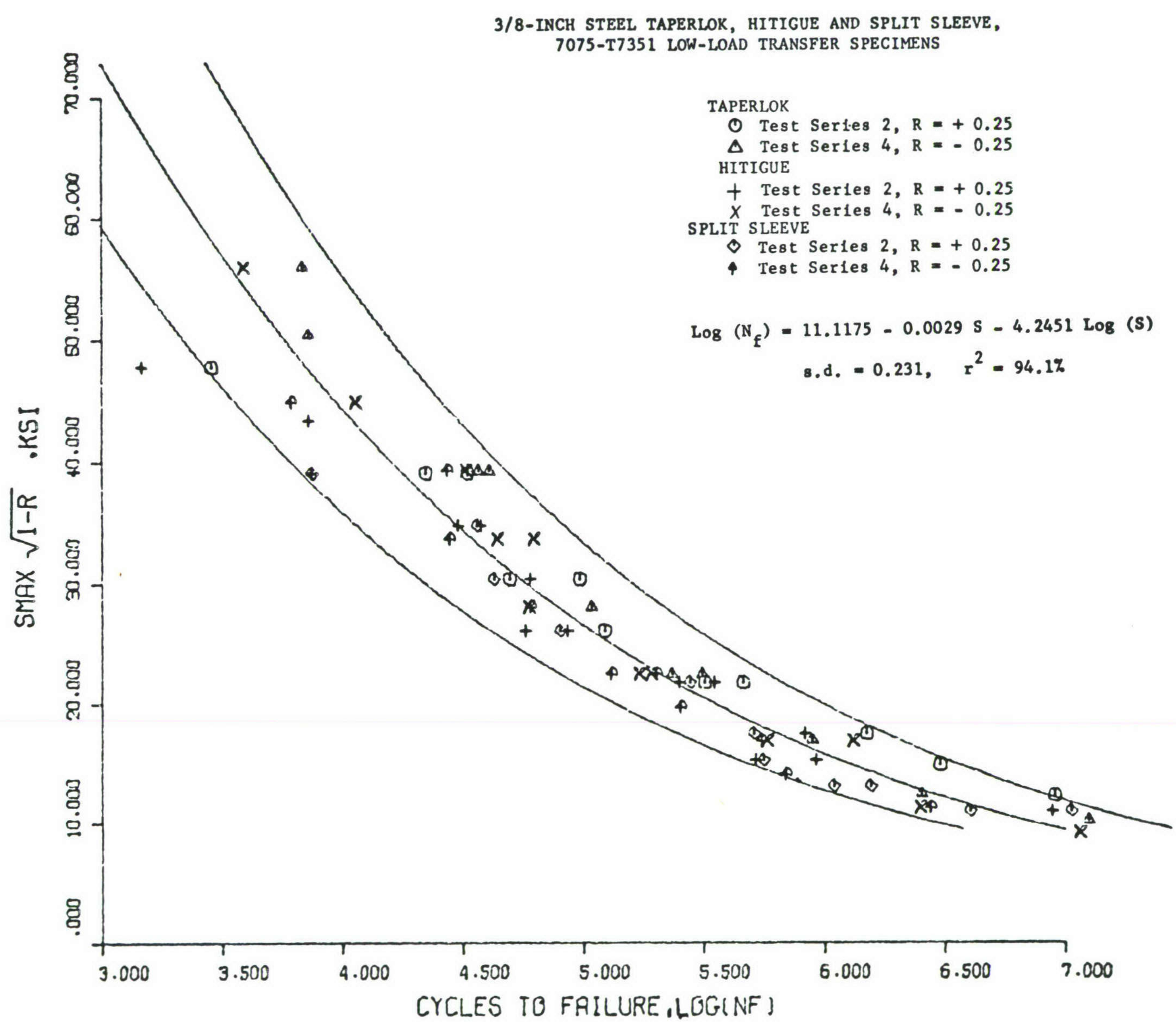



FIGURE B-25. FASTENER FATIGUE IMPROVEMENT DATA

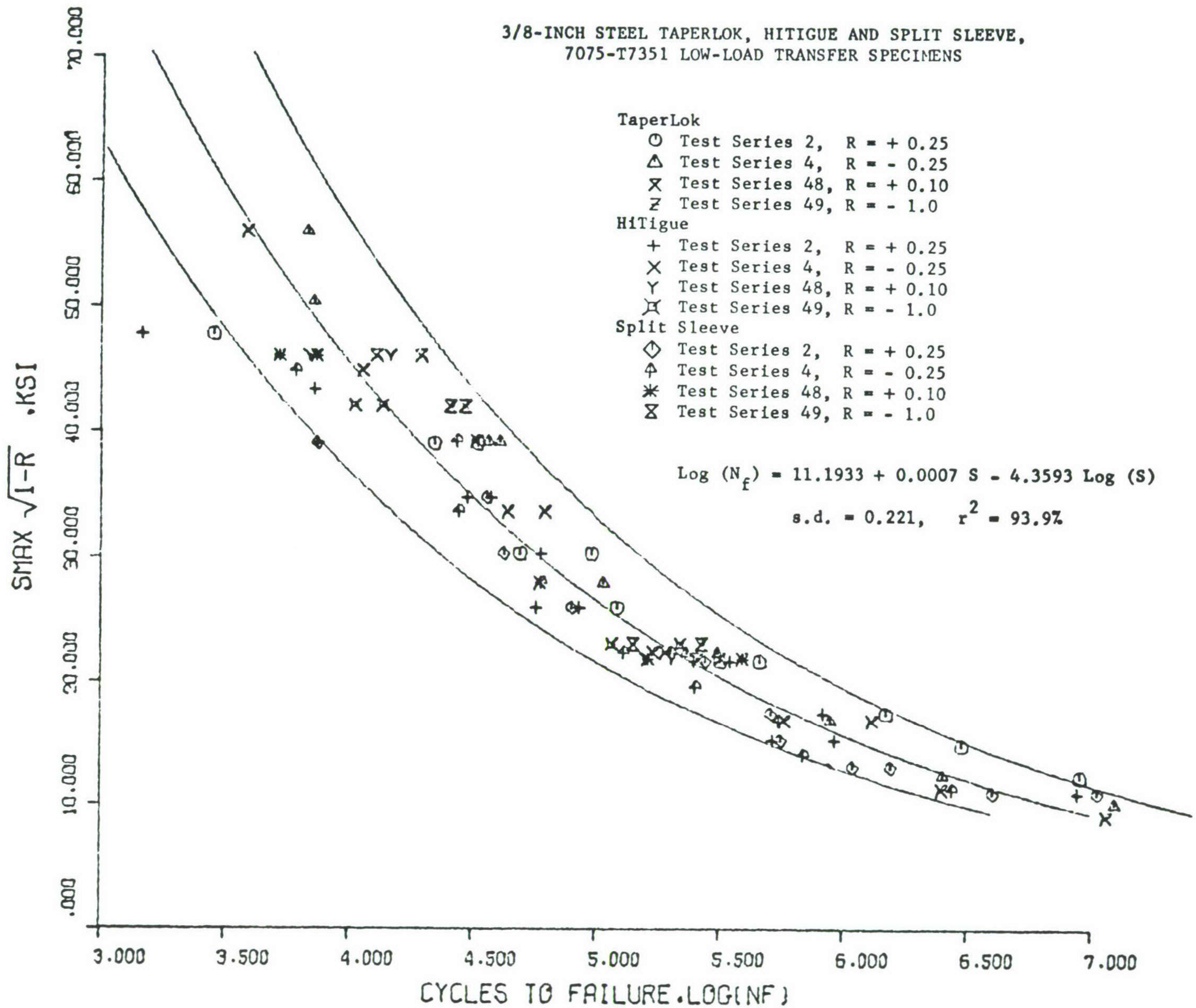



FIGURE B-26. FASTENER FATIGUE IMPROVEMENT DATA

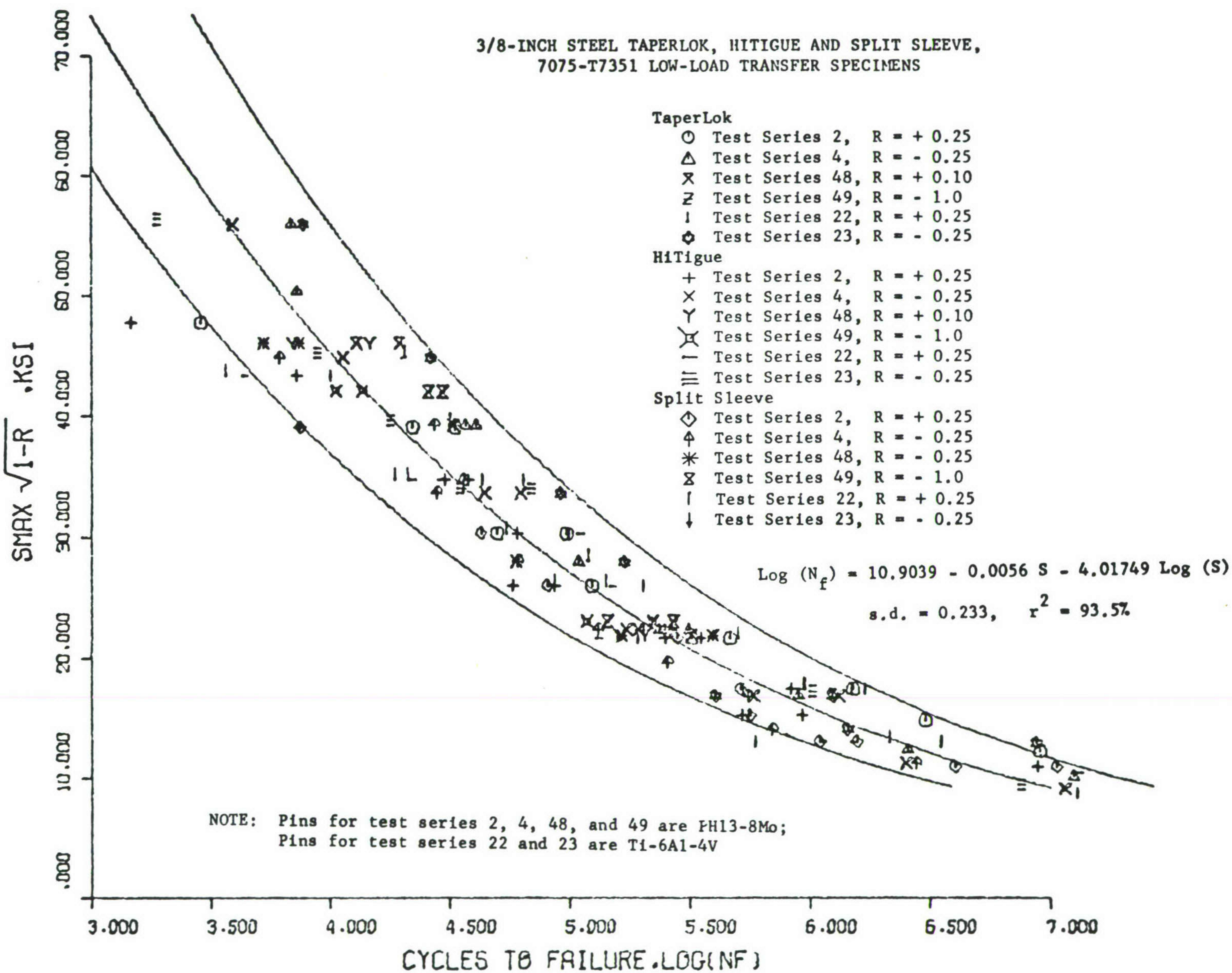



FIGURE B-27. FASTENER FATIGUE IMPROVEMENT DATA

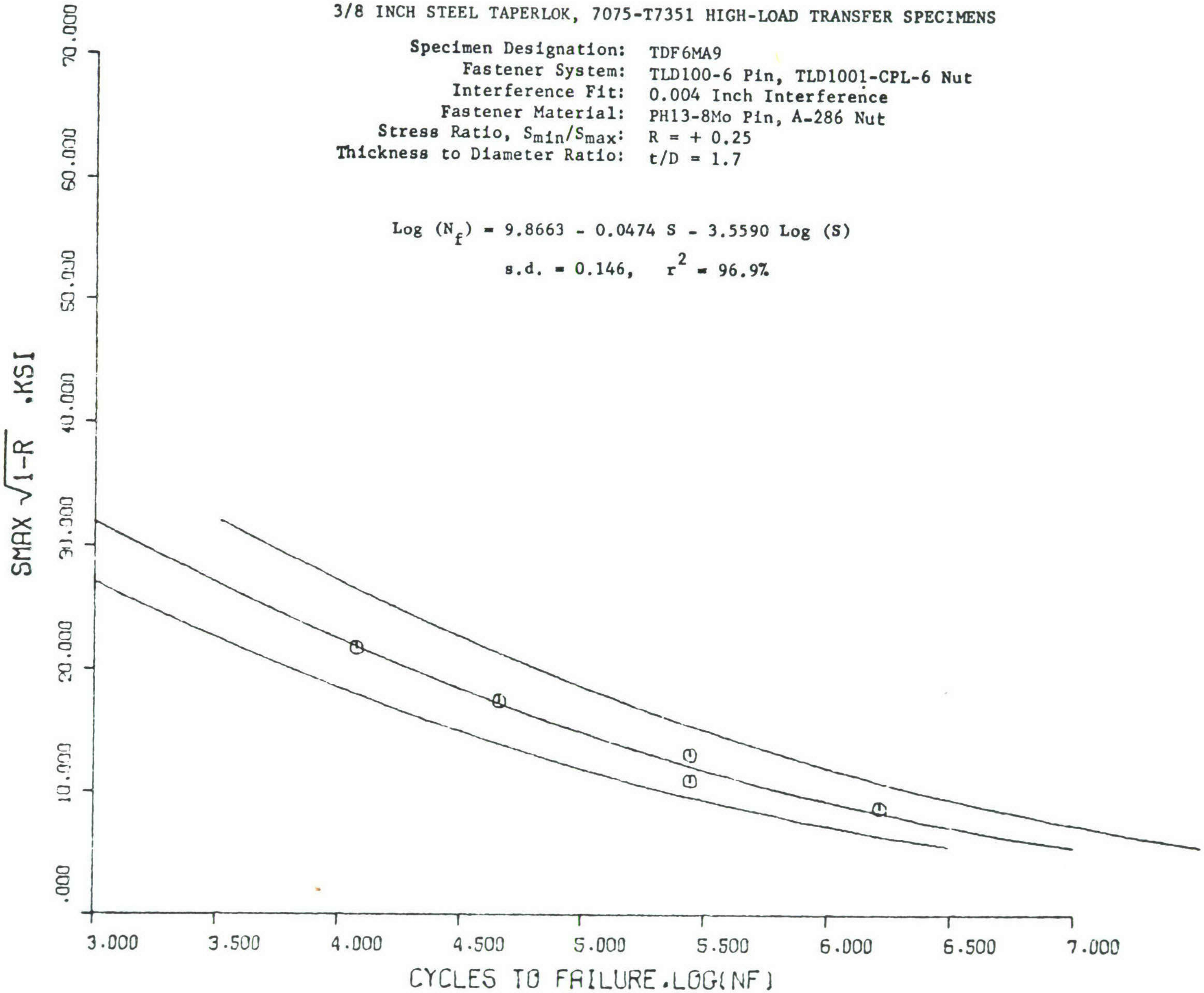



FIGURE B-28. FASTENER FATIGUE IMPROVEMENT DATA

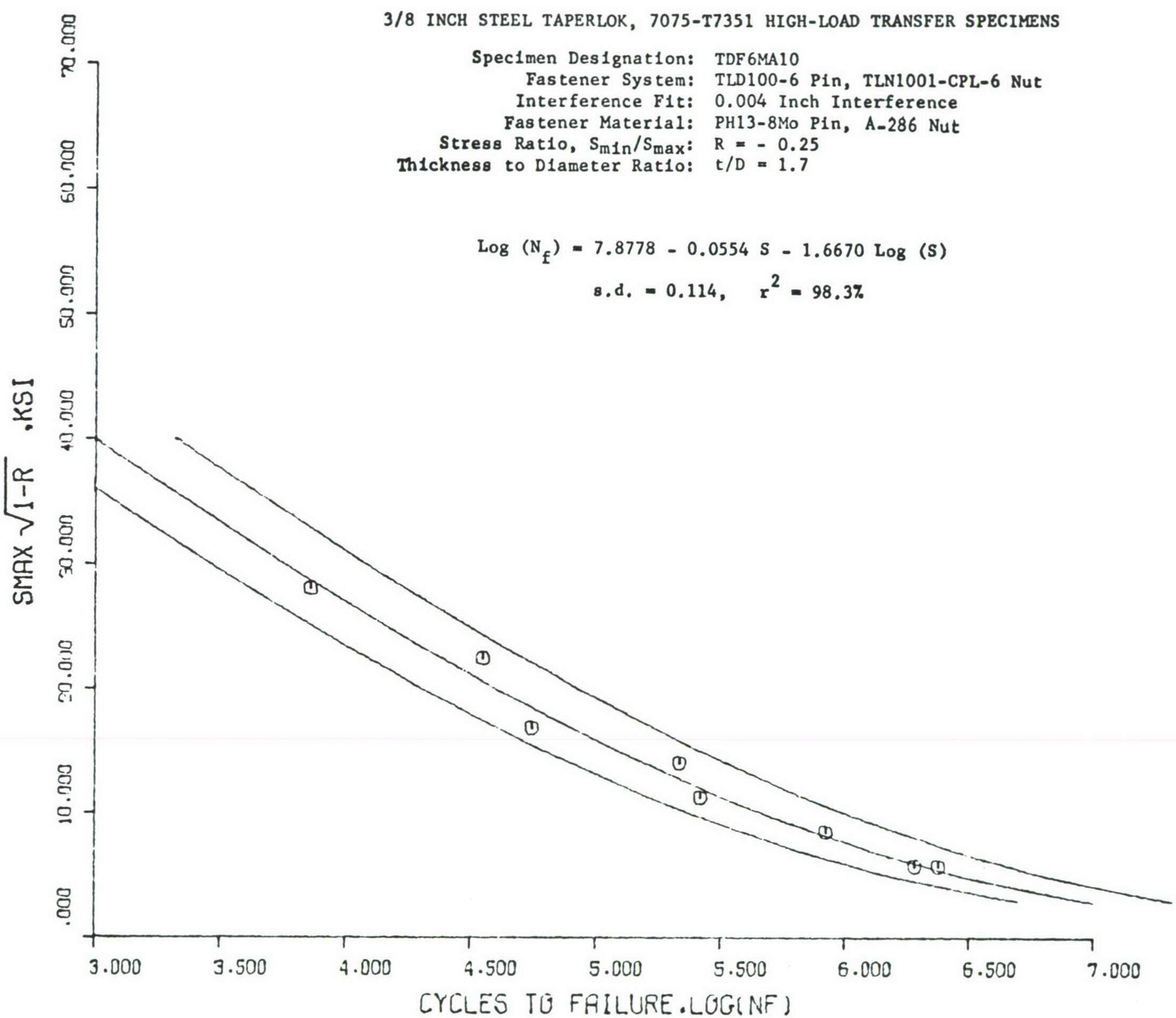



FIGURE B-29. FASTENER FATIGUE IMPROVEMENT DATA

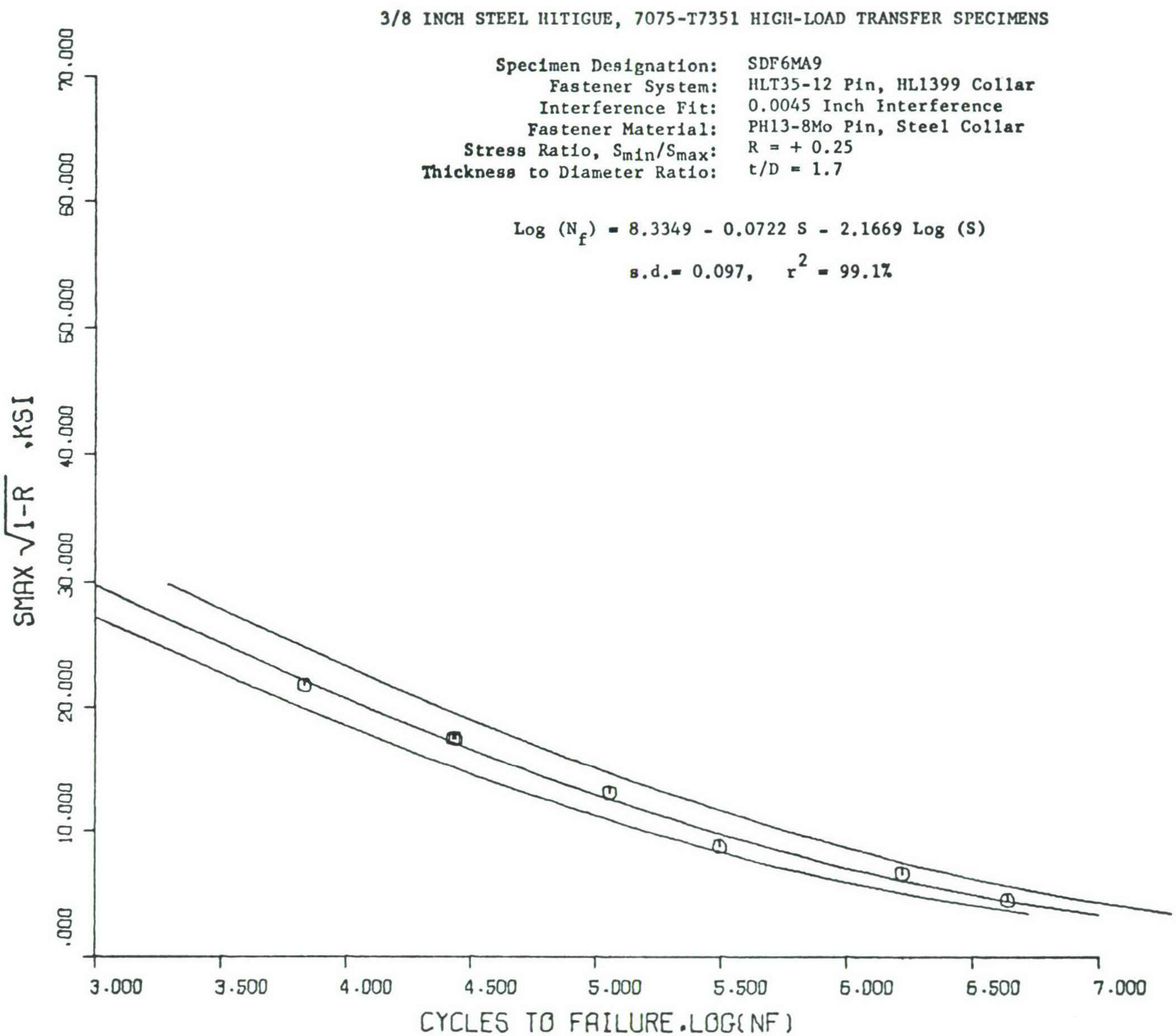



FIGURE B-30. FASTENER FATIGUE IMPROVEMENT DATA

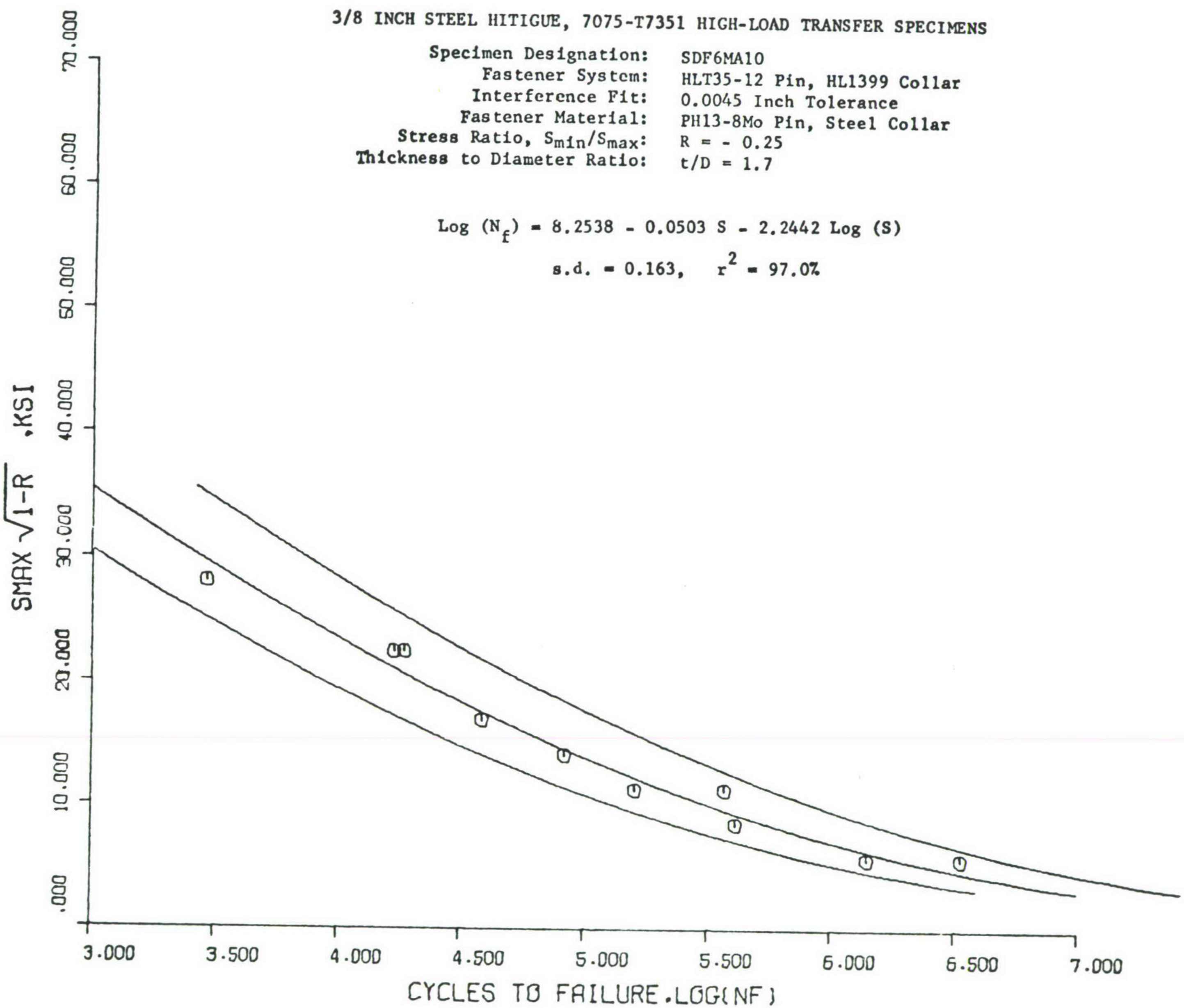
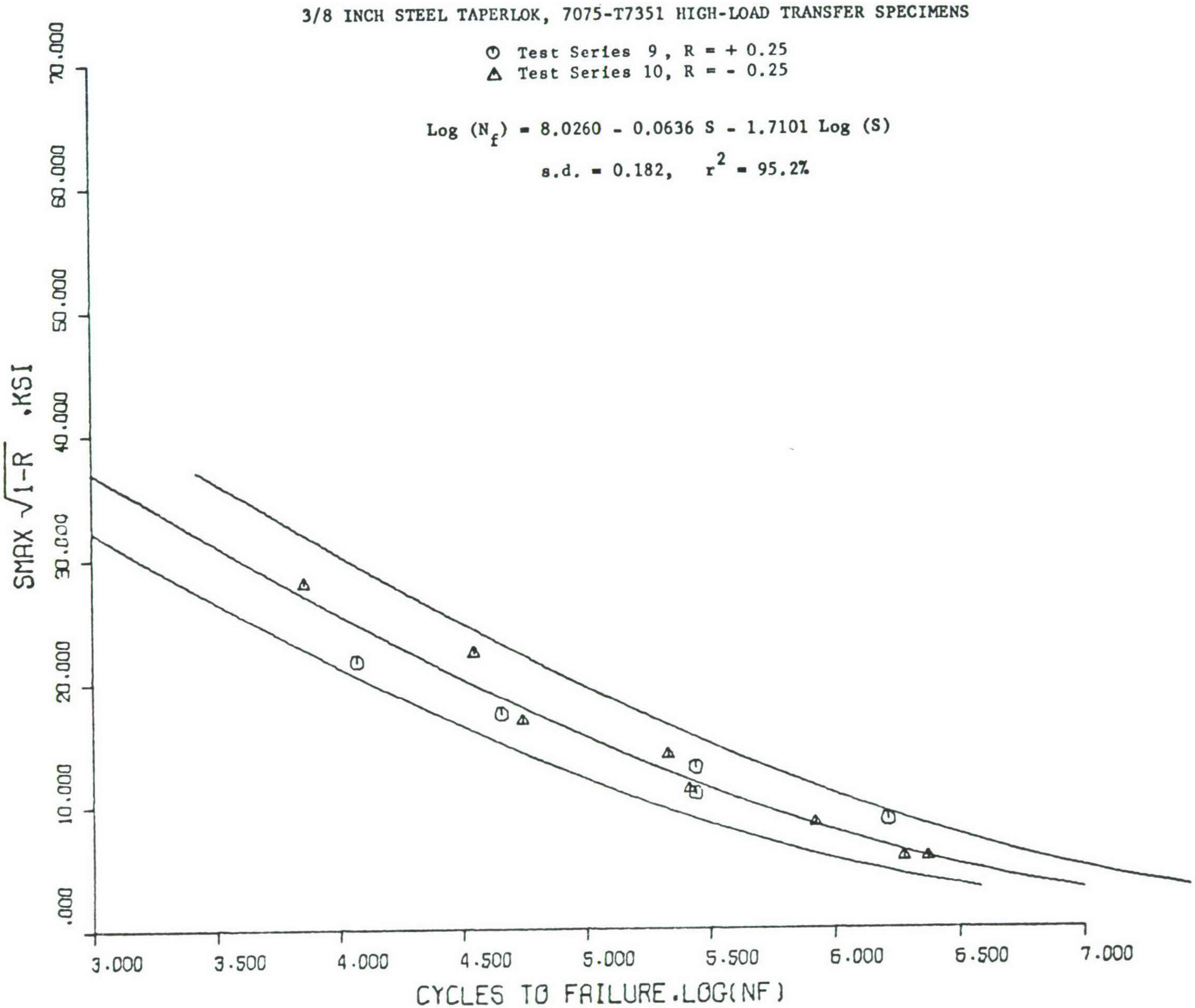



FIGURE B-31. FASTENER FATIGUE IMPROVEMENT DATA




FIGUBE B-32. FASTENER FATIGUE IMPROVEMENT DATA

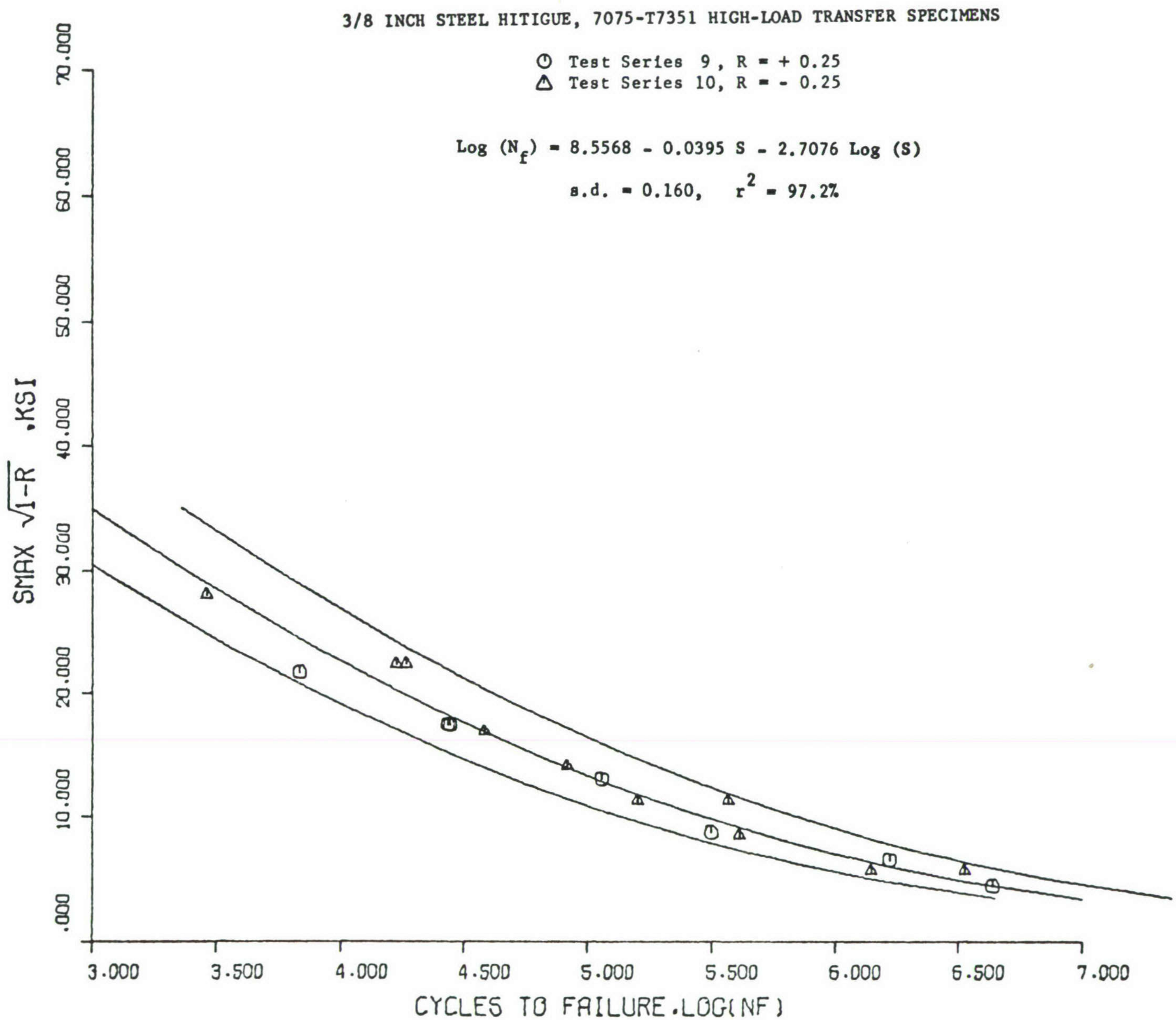



FIGURE B-33. FASTENER FATIGUE IMPROVEMENT DATA

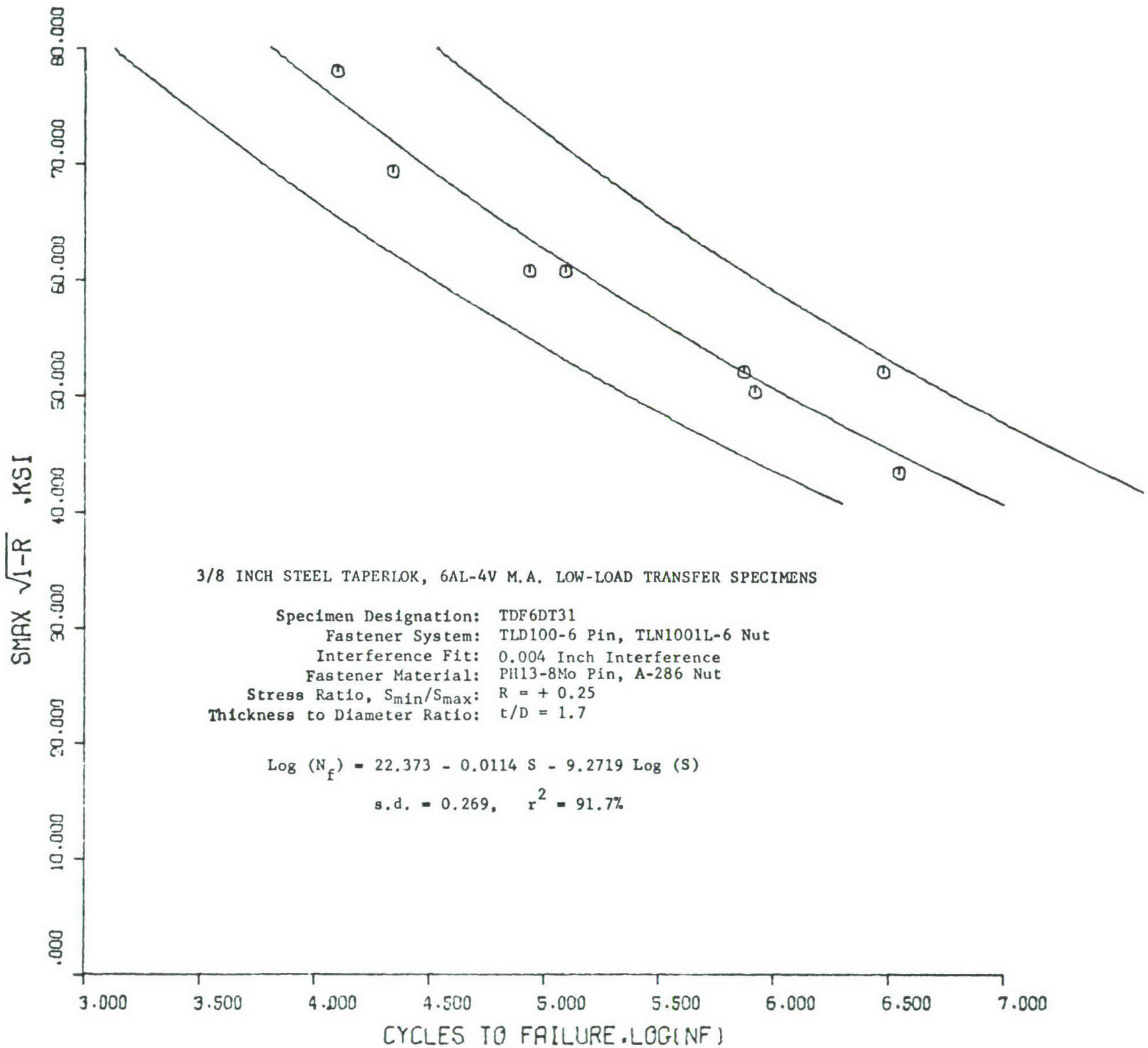



FIGURE B-34. FASTENER FATIGUE IMPROVEMENT DATA

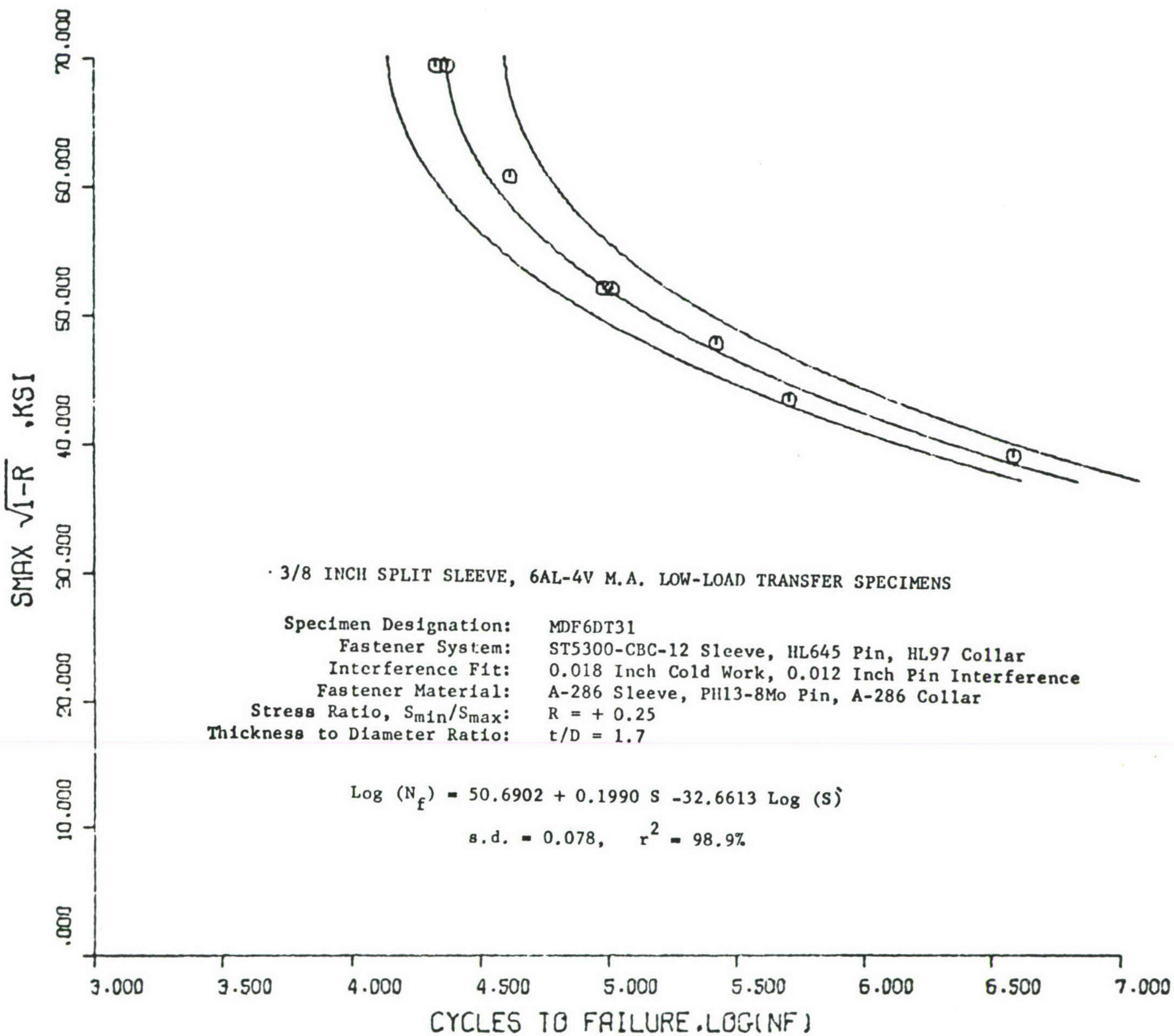



FIGURE B-35. FASTENER FATIGUE IMPROVEMENT DATA

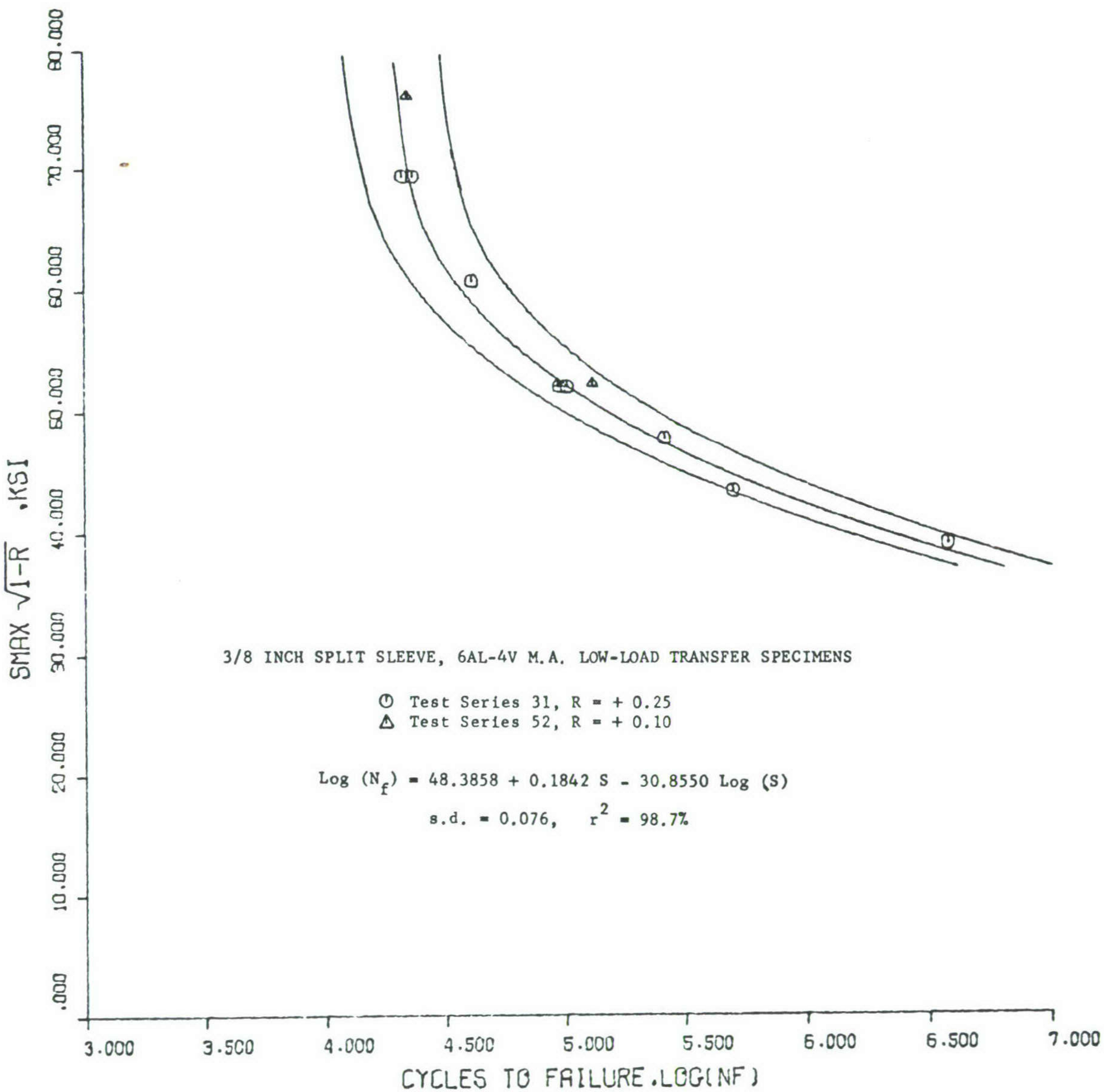



FIGURE B-36. FASTENER FATIGUE IMPROVEMENT DATA

APPENDIX C

## FATIGUE LIFE CURVES FOR SECONDARY VARIABLES

Mean life and 90 percent population limits for Figures C-1 through C-18 are defined by Figure B-27 where:

$$Log(N_f) = 10.9039 - 0.0056S - 4.01749\ Log(S).$$

Mean life and 90 percent population limits for Figures C-19 through C-22 are defined by Figure B-34 where:

$$Log(N_f) = 22.373 - 0.0144S - 9.2719\ Log(S).$$

Mean life and 90 percent population limits for Figure C-23 is defined by Figure B-36 where:

$$Log(N_f) = 48.3858 + 0.1842S - 30.8550\ Log(S).$$

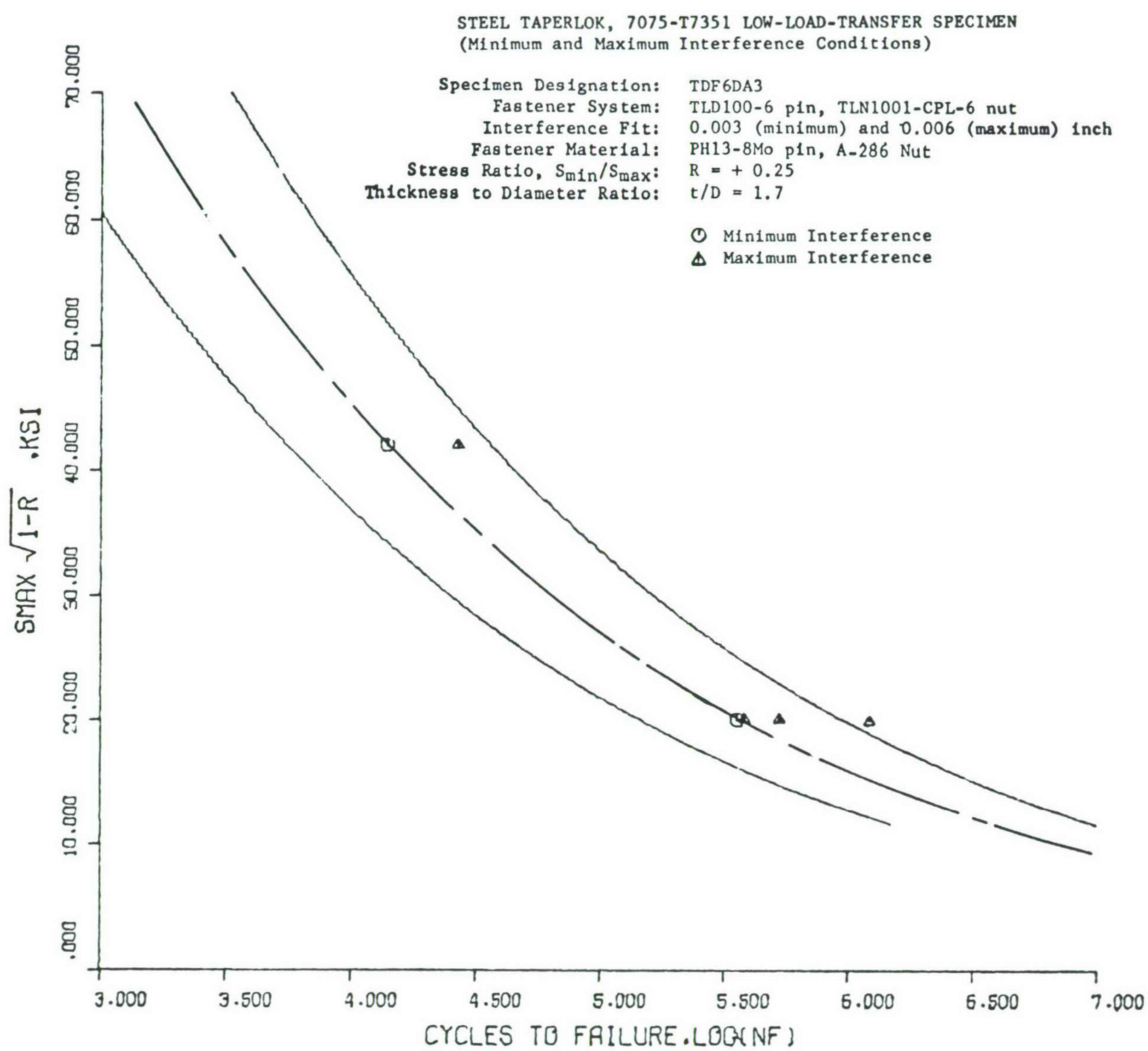



FIGURE C-1. FASTENER FATIGUE IMPROVEMENT DATA

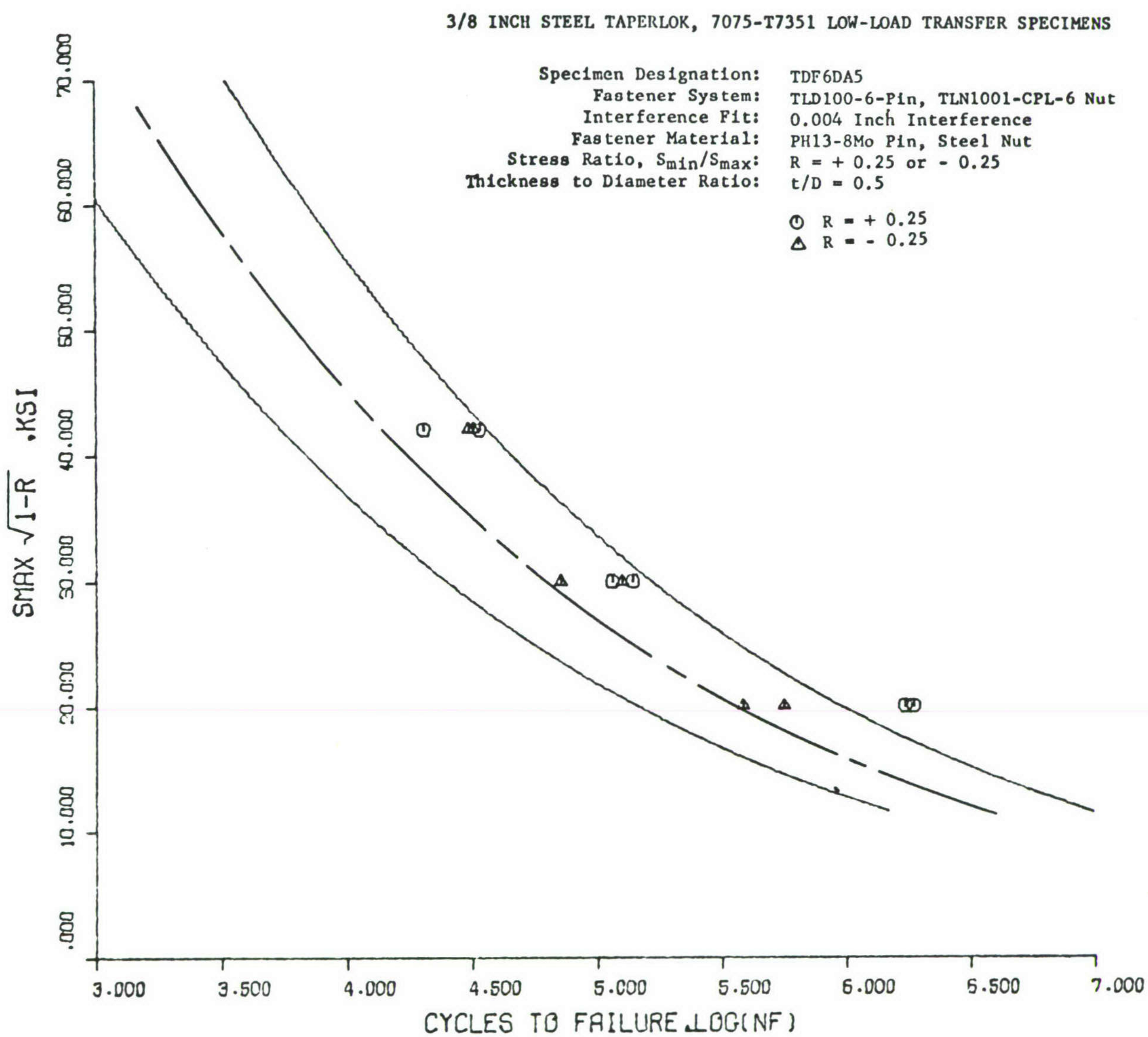



FIGURE C-2. FASTENER FATIGUE IMPROVEMENT DATA

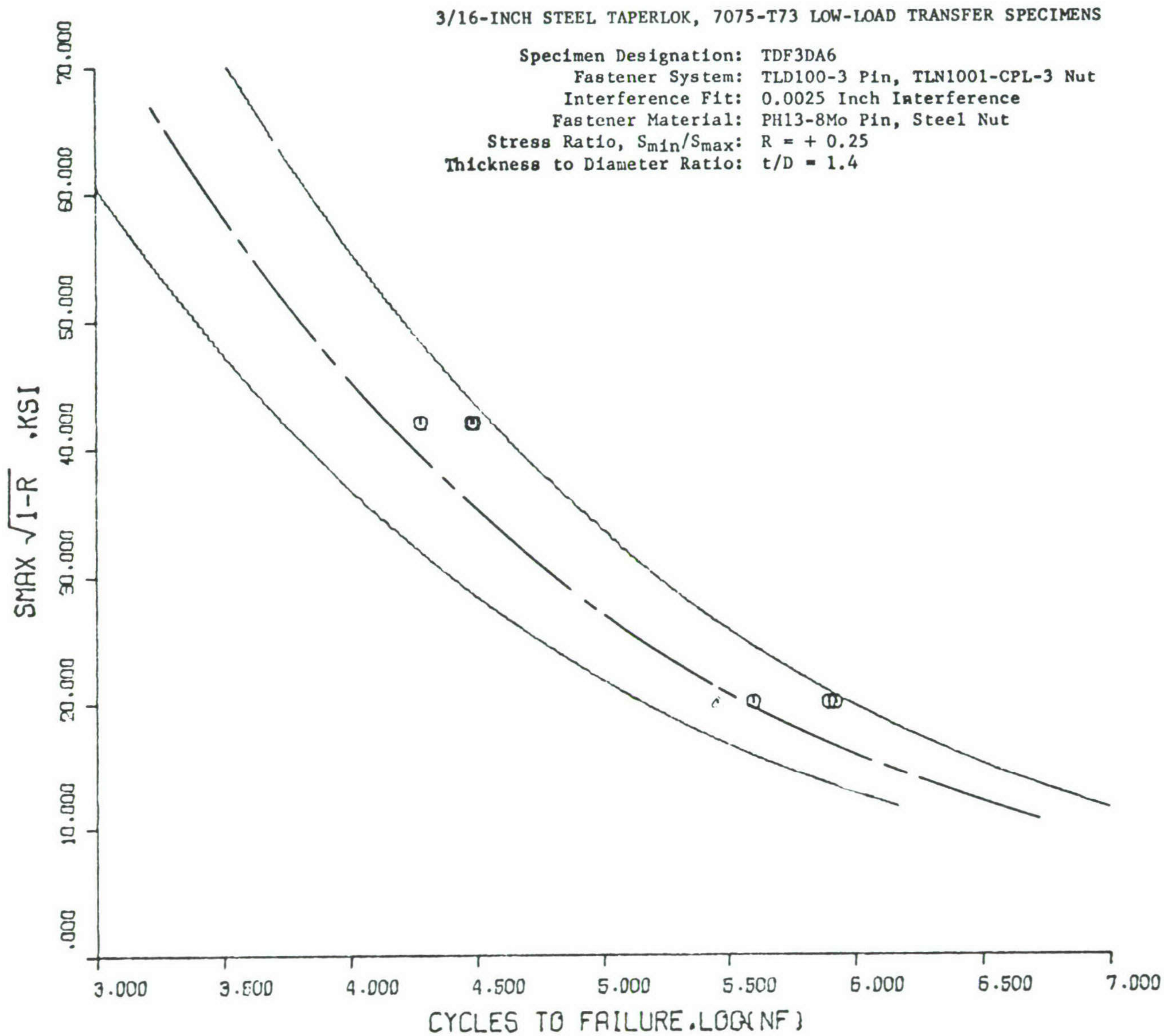



FIGURE C-3. FASTENER FATIGUE IMPROVEMENT DATA

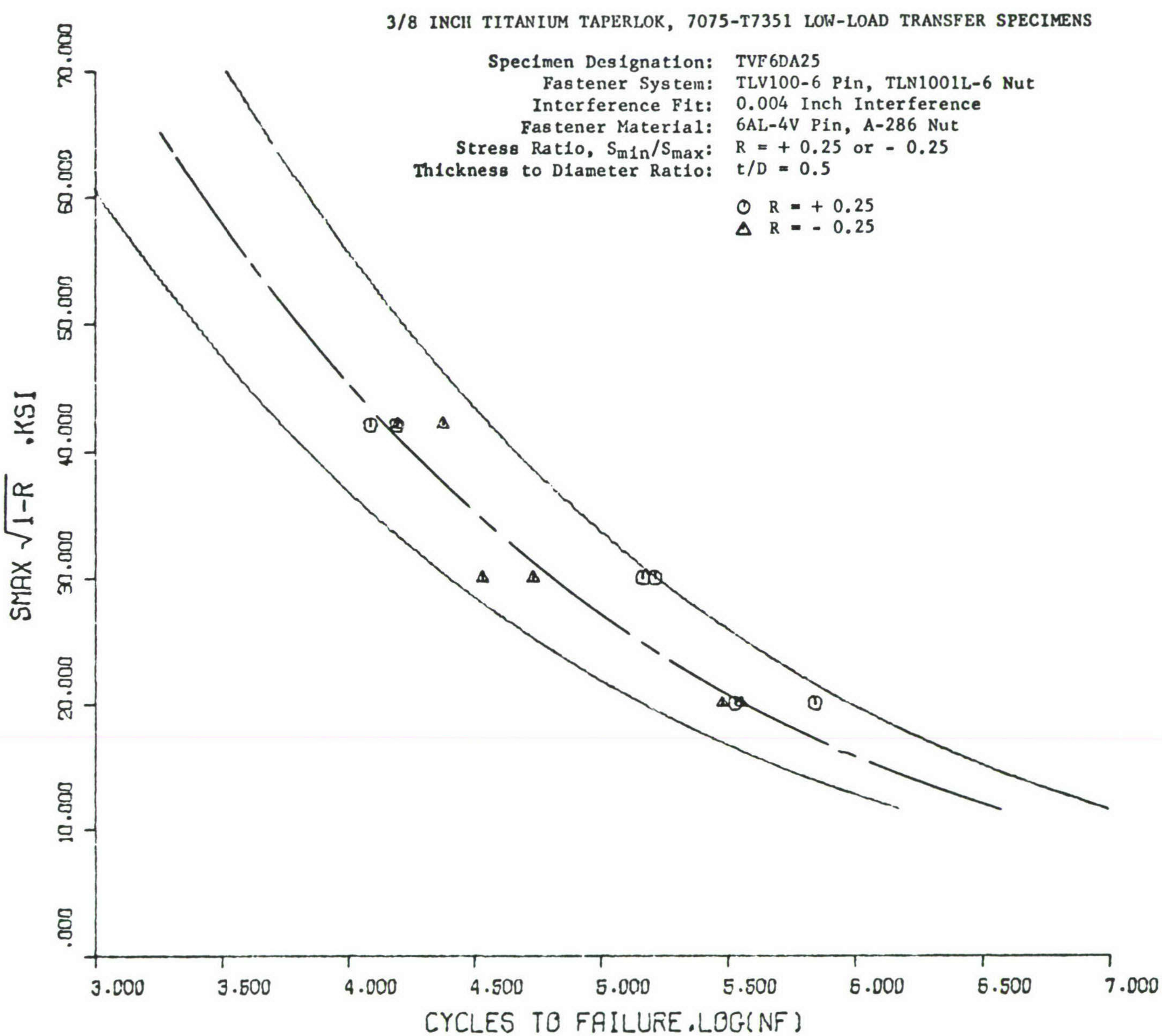



FIGURE C-4. FASTENER FATIGUE IMPROVEMENT DATA

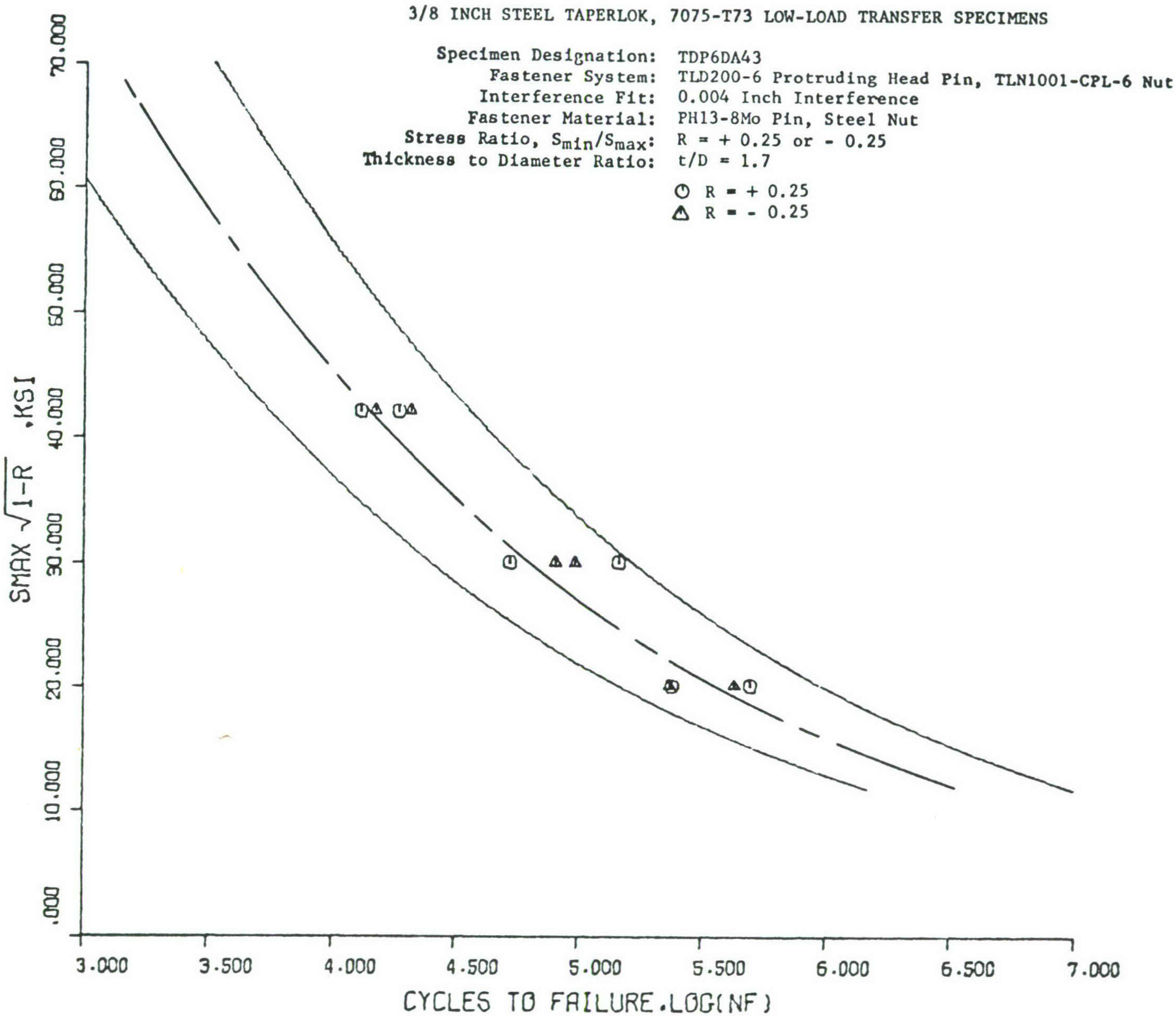



FIGURE C-5. FASTENER FATIGUE IMPROVEMENT DATA

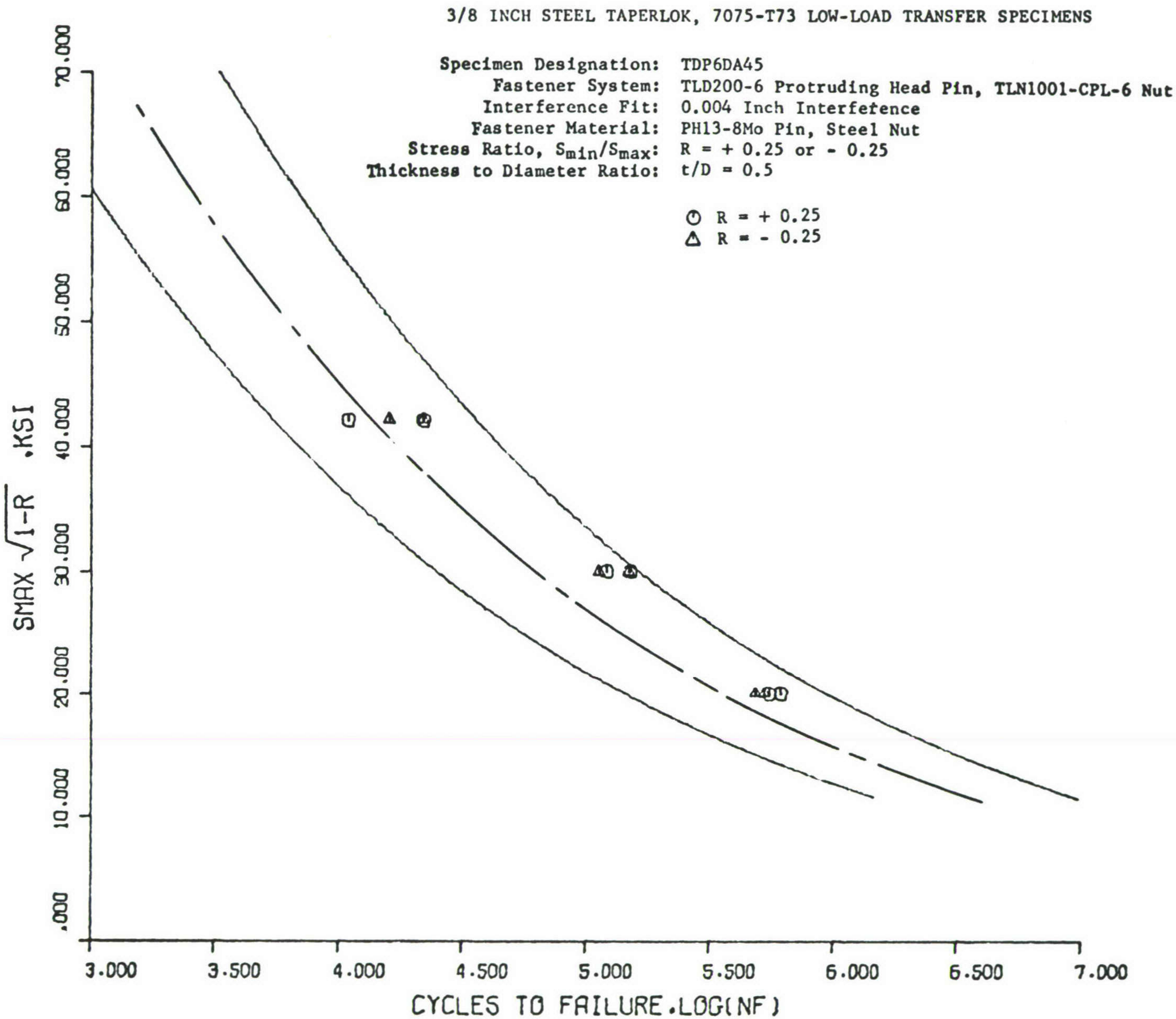



FIGURE C-6. FASTENER FATIGUE IMPROVEMENT DATA

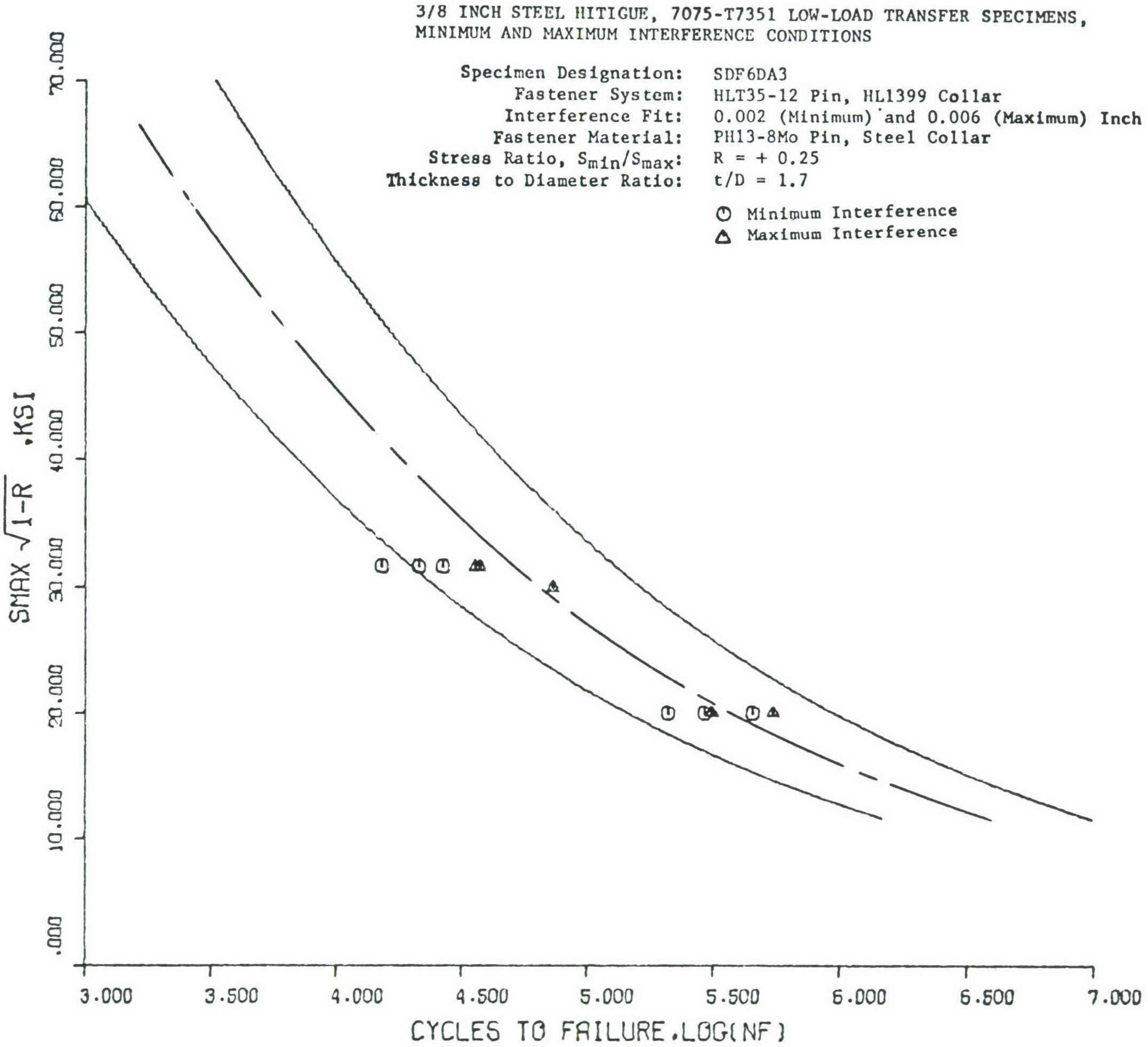



FIGURE C-7. FASTENER FATIGUE IMPROVEMENT DATA

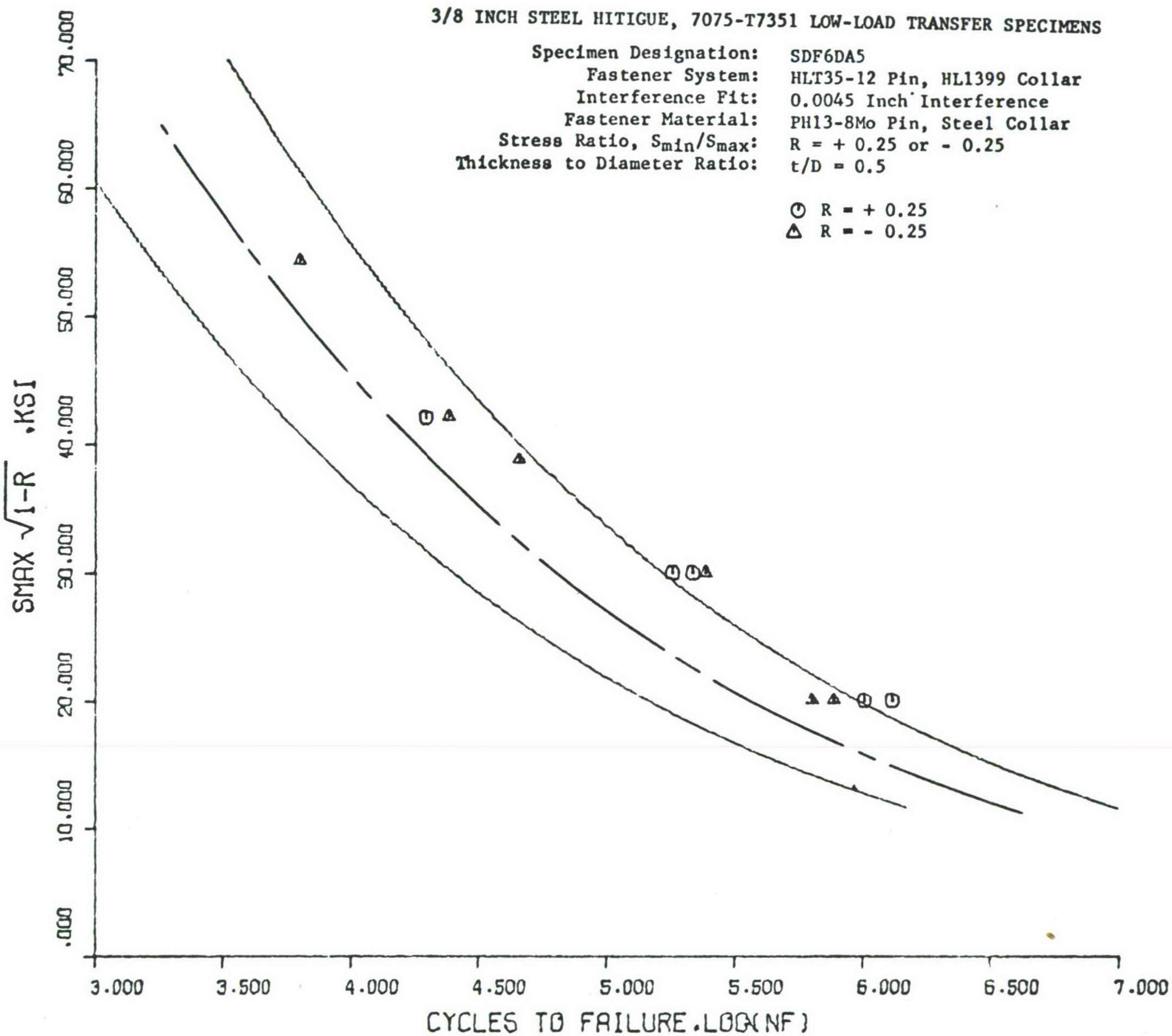



FIGURE C-8. FASTENER FATIGUE IMPROVEMENT DATA

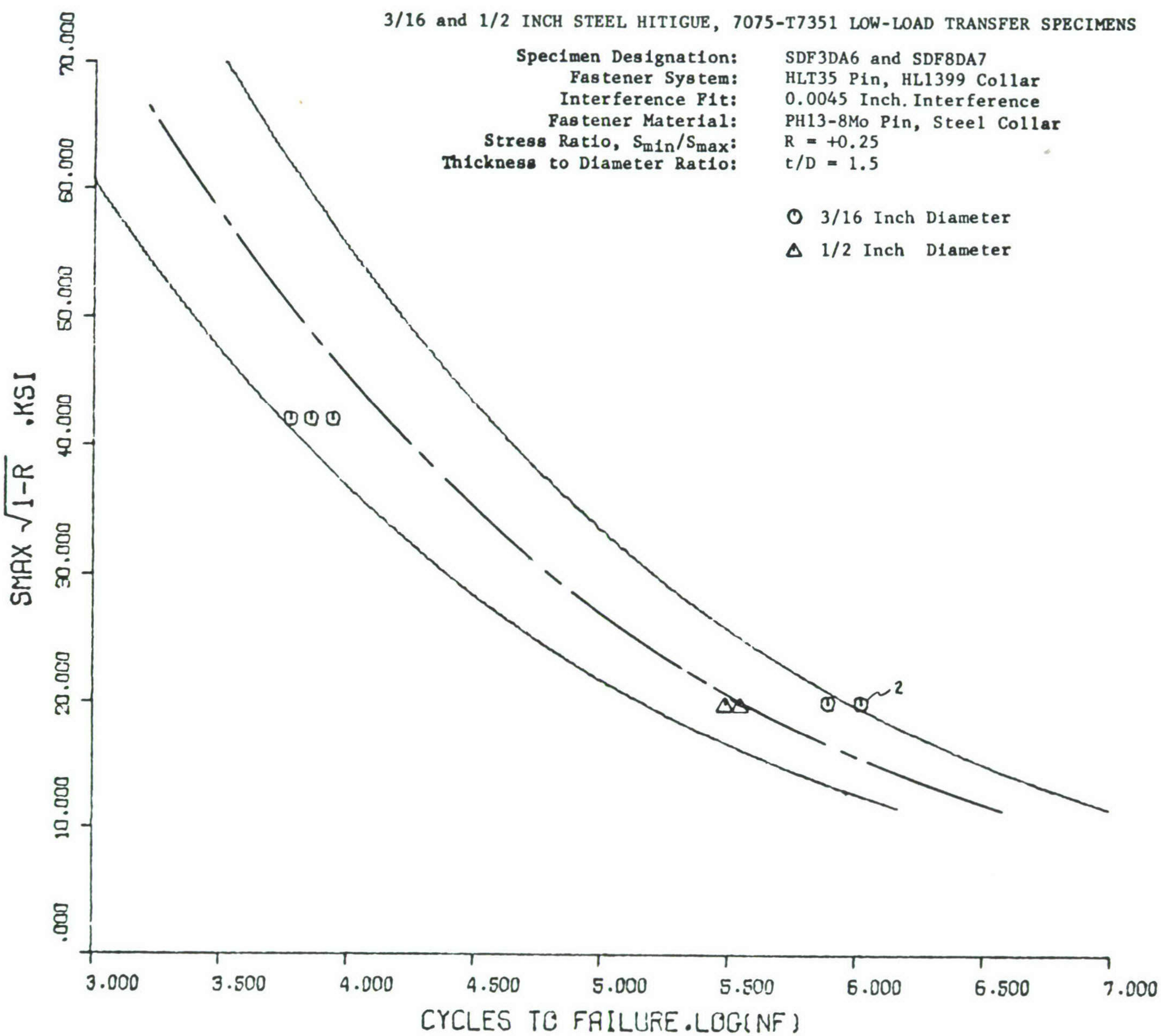



FIGURE C-9. FASTENER FATIGUE IMPROVEMENT DATA

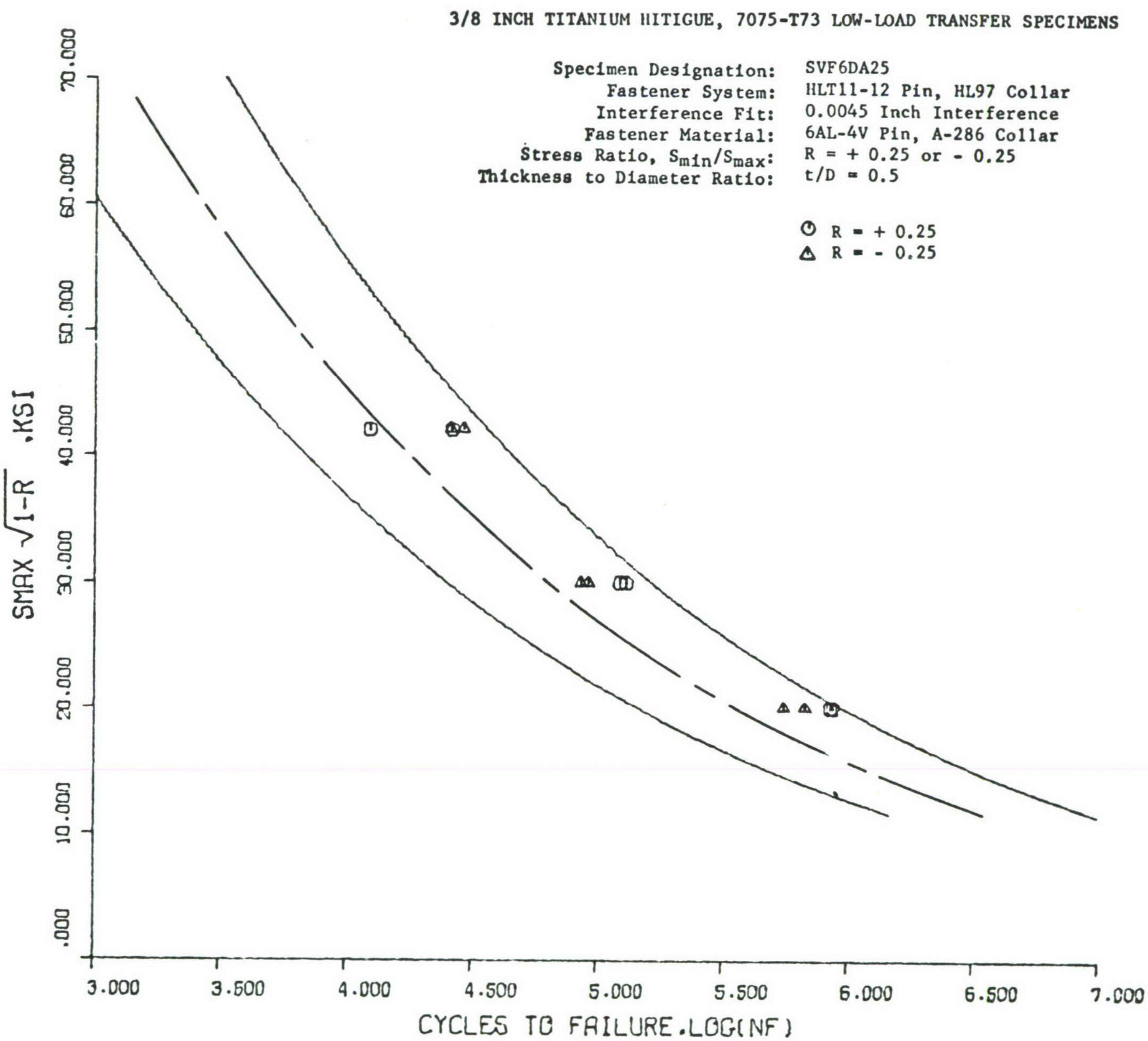



FIGURE C-10. FASTENER FATIGUE IMPROVEMENT DATA

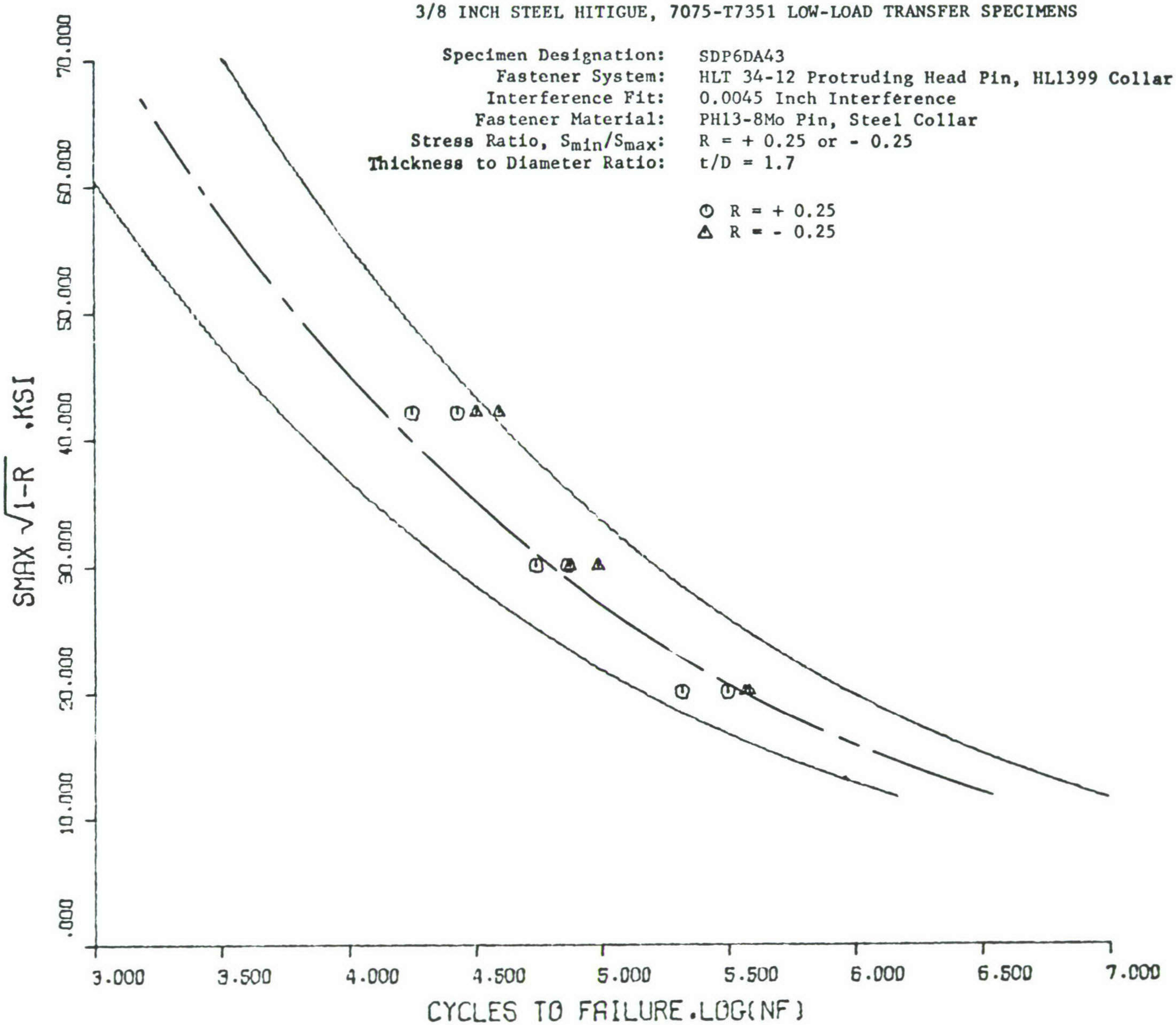



FIGURE C-11. FASTENER FATIGUE IMPROVEMENT DATA

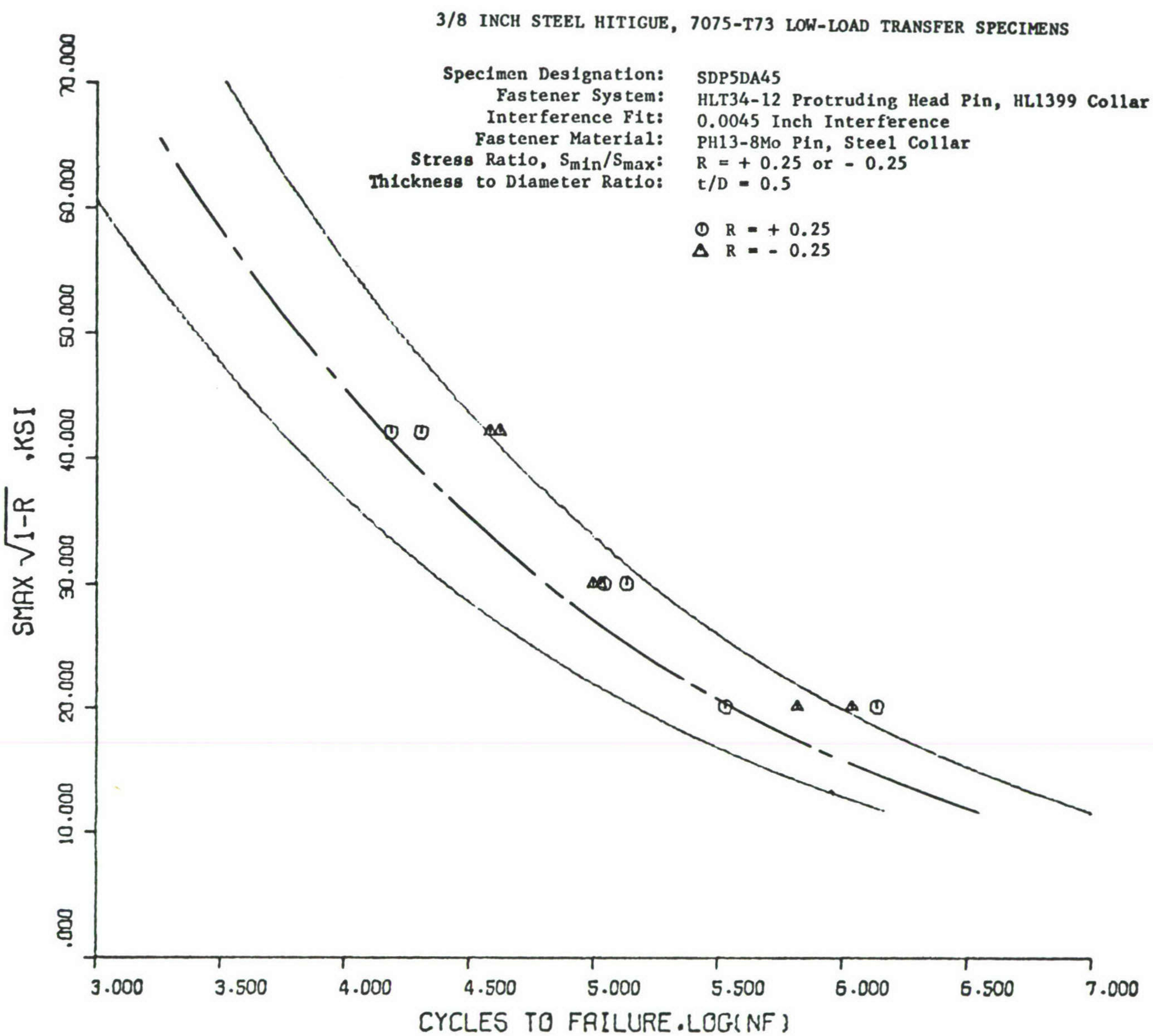



FIGURE C-12. FASTENER FATIGUE IMPROVEMENT DATA

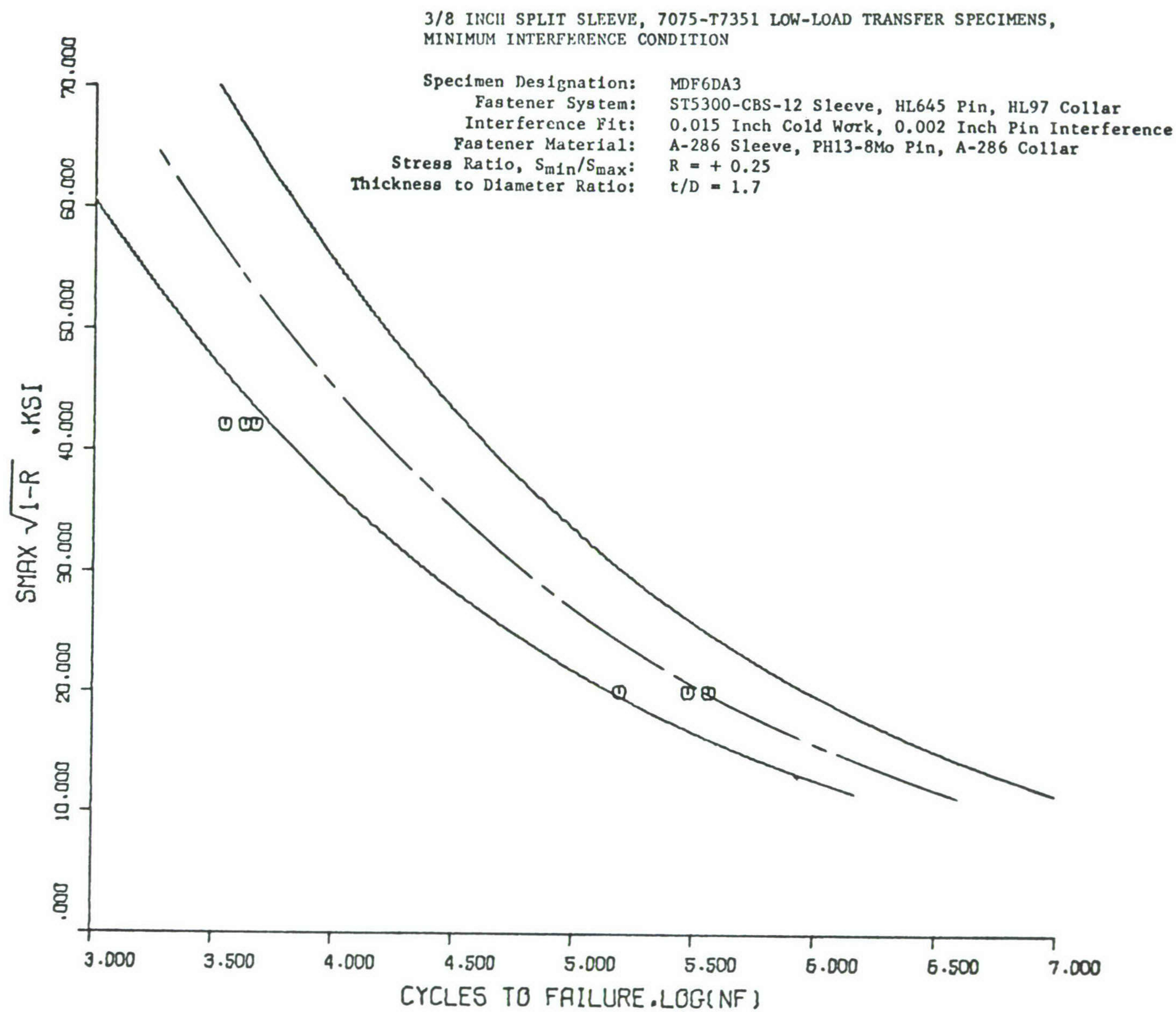



FIGURE C-13. FASTENER FATIGUE IMPROVEMENT DATA

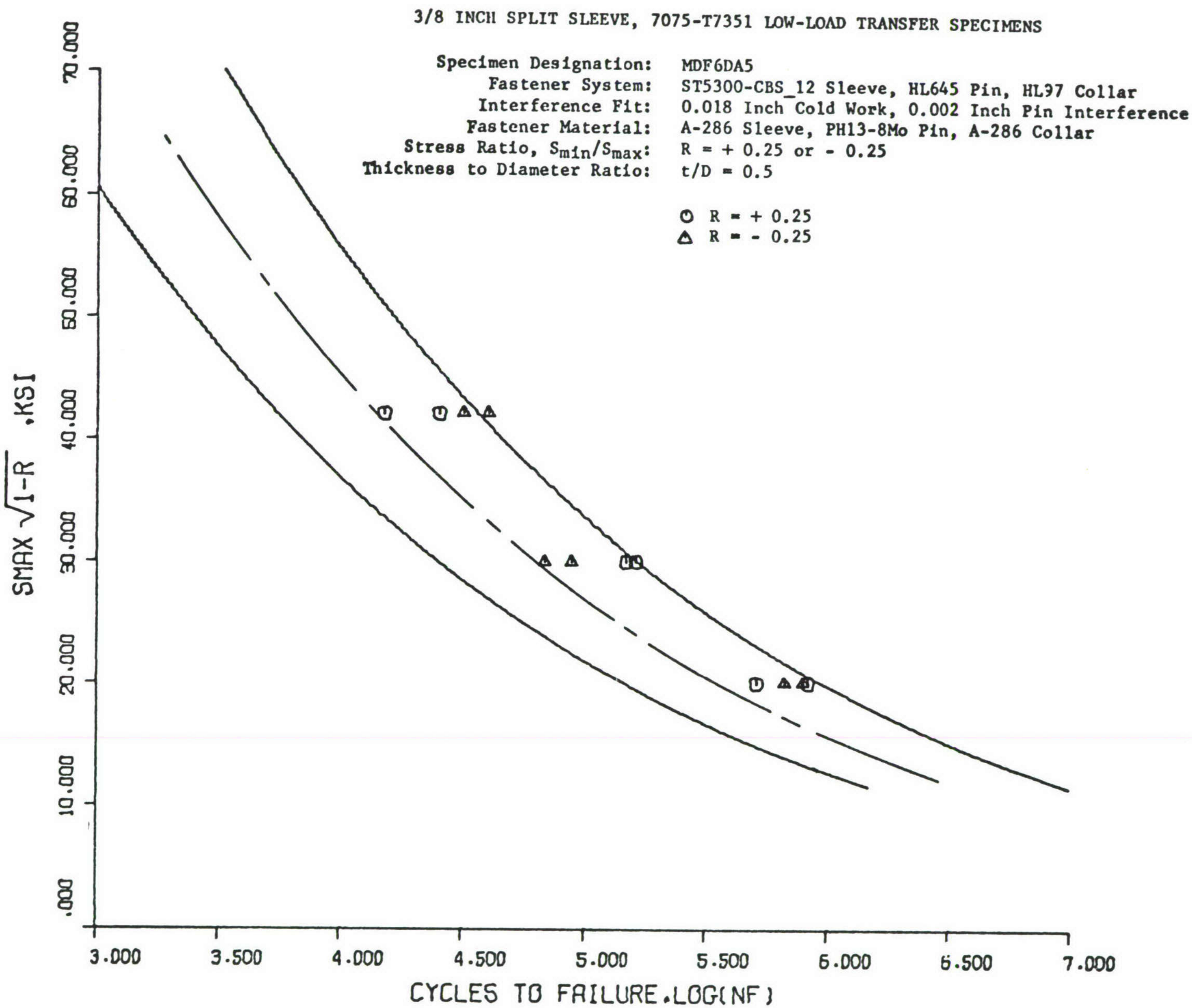



FIGURE C-14. FASTENER FATIGUE IMPROVEMENT DATA

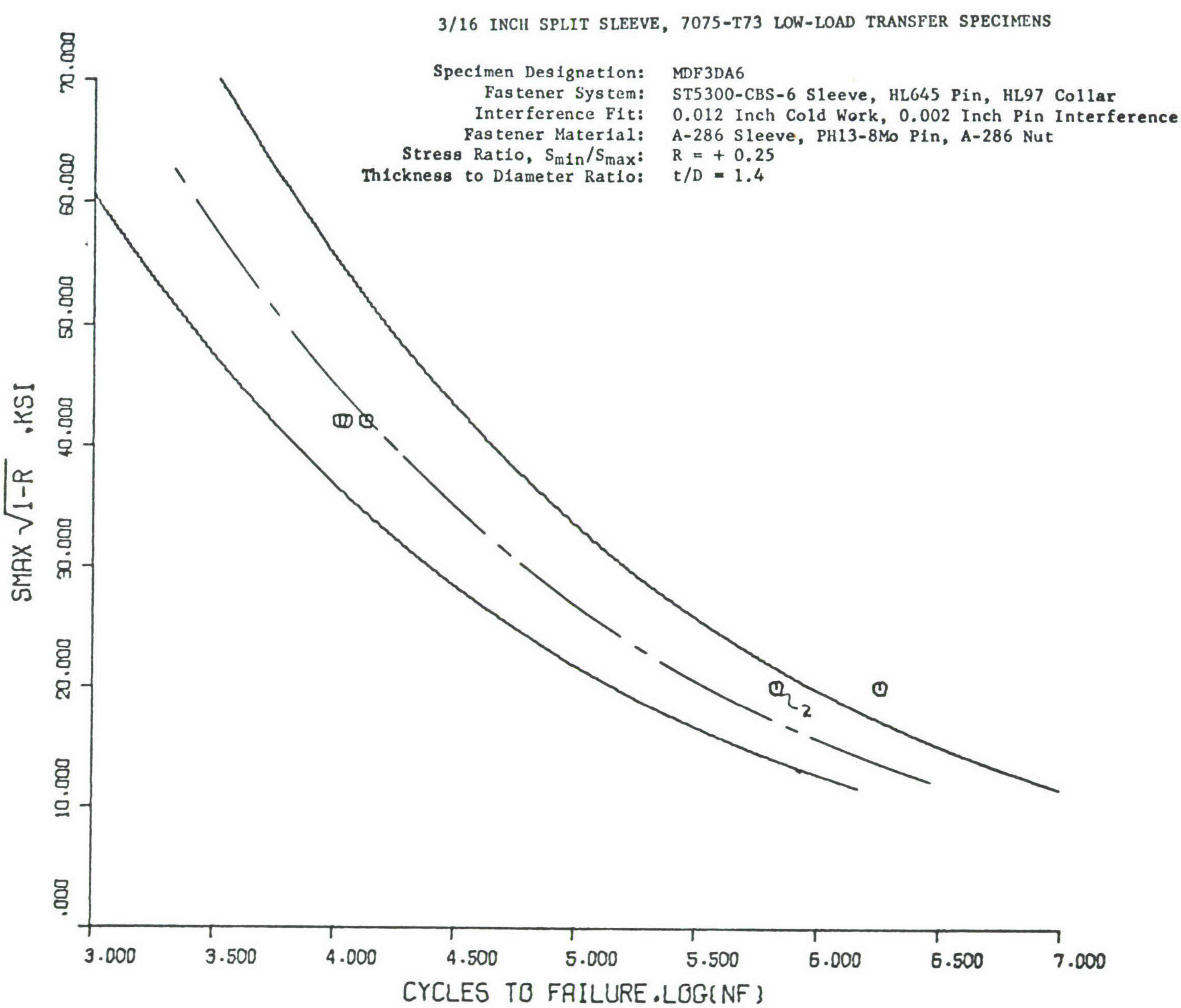



FIGURE C-15. FASTENER FATIGUE IMPROVEMENT DATA

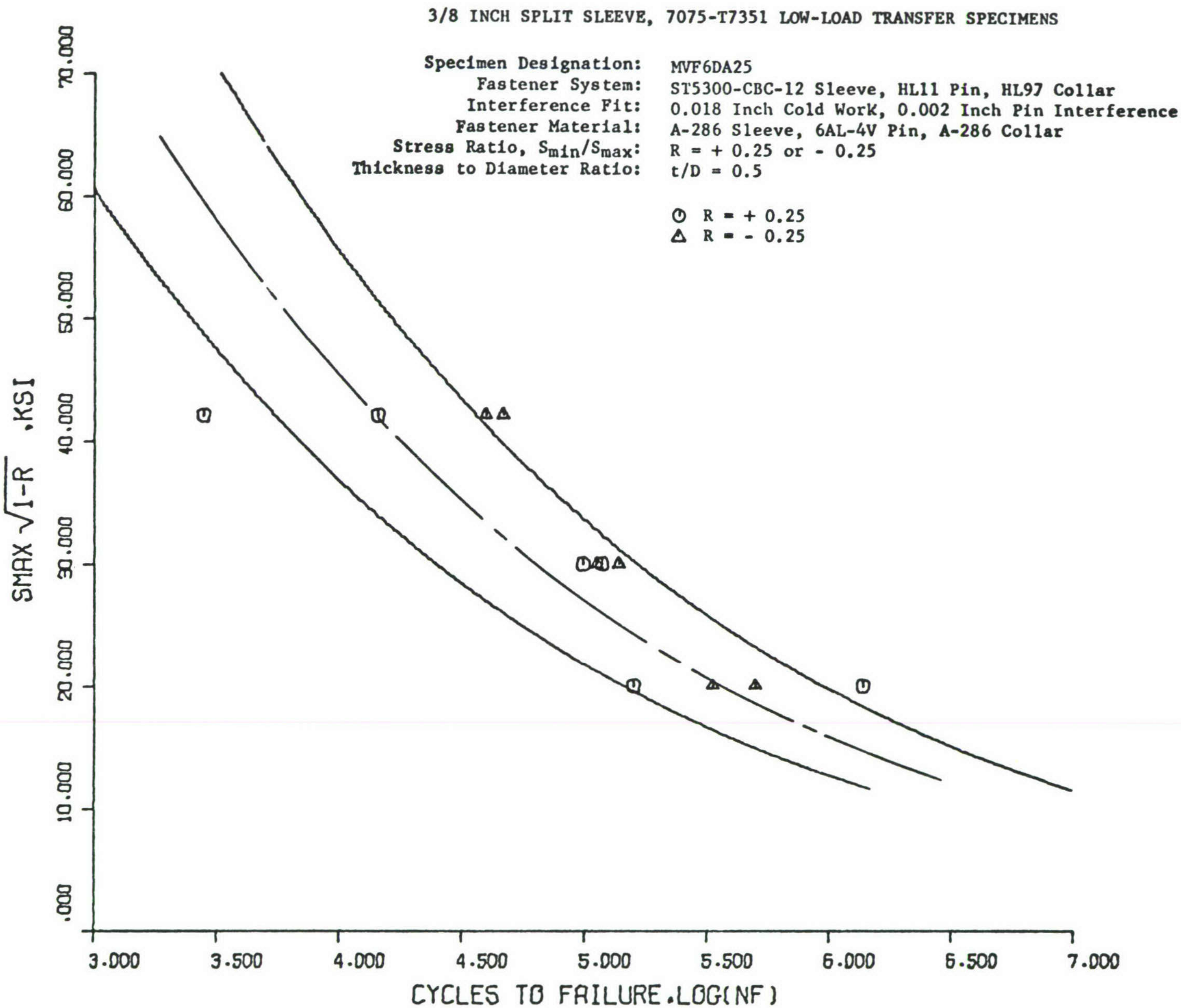



FIGURE C-16. FASTENER FATIGUE IMPROVEMENT DATA

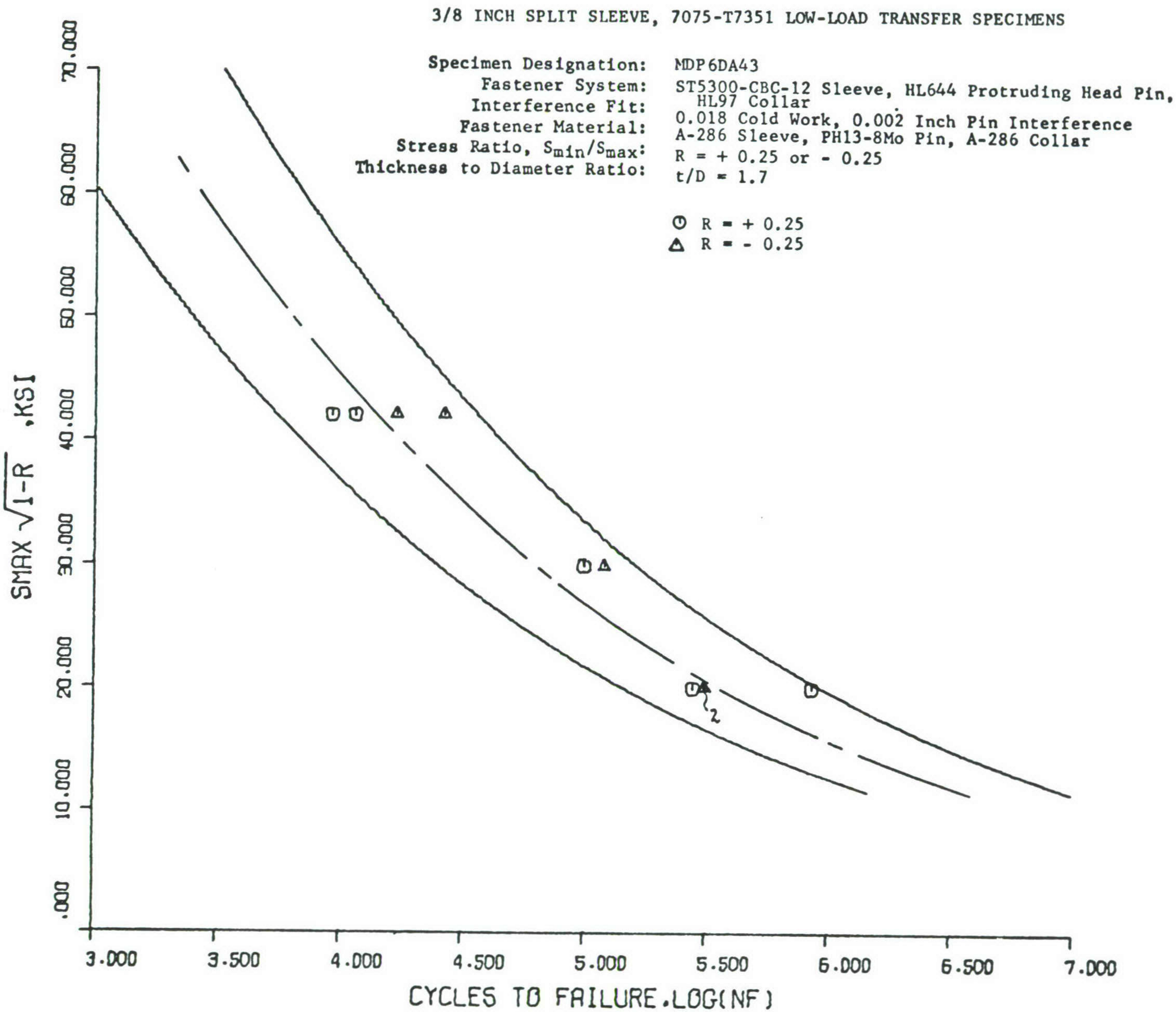



FIGURE C-17. FASTENER FATIGUE IMPROVEMENT DATA

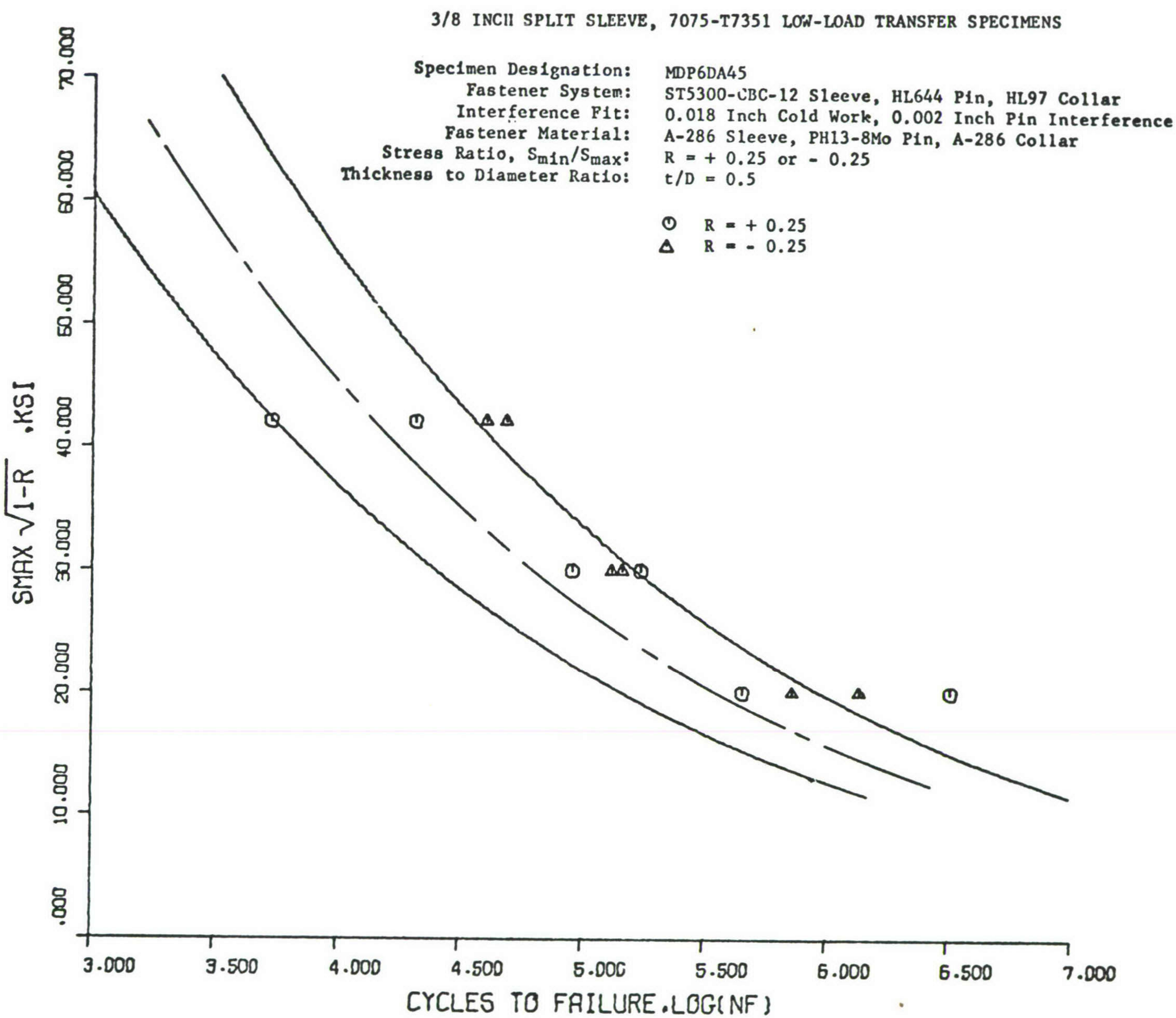



FIGURE C-18. FASTENER FATIGUE IMPROVEMENT DATA

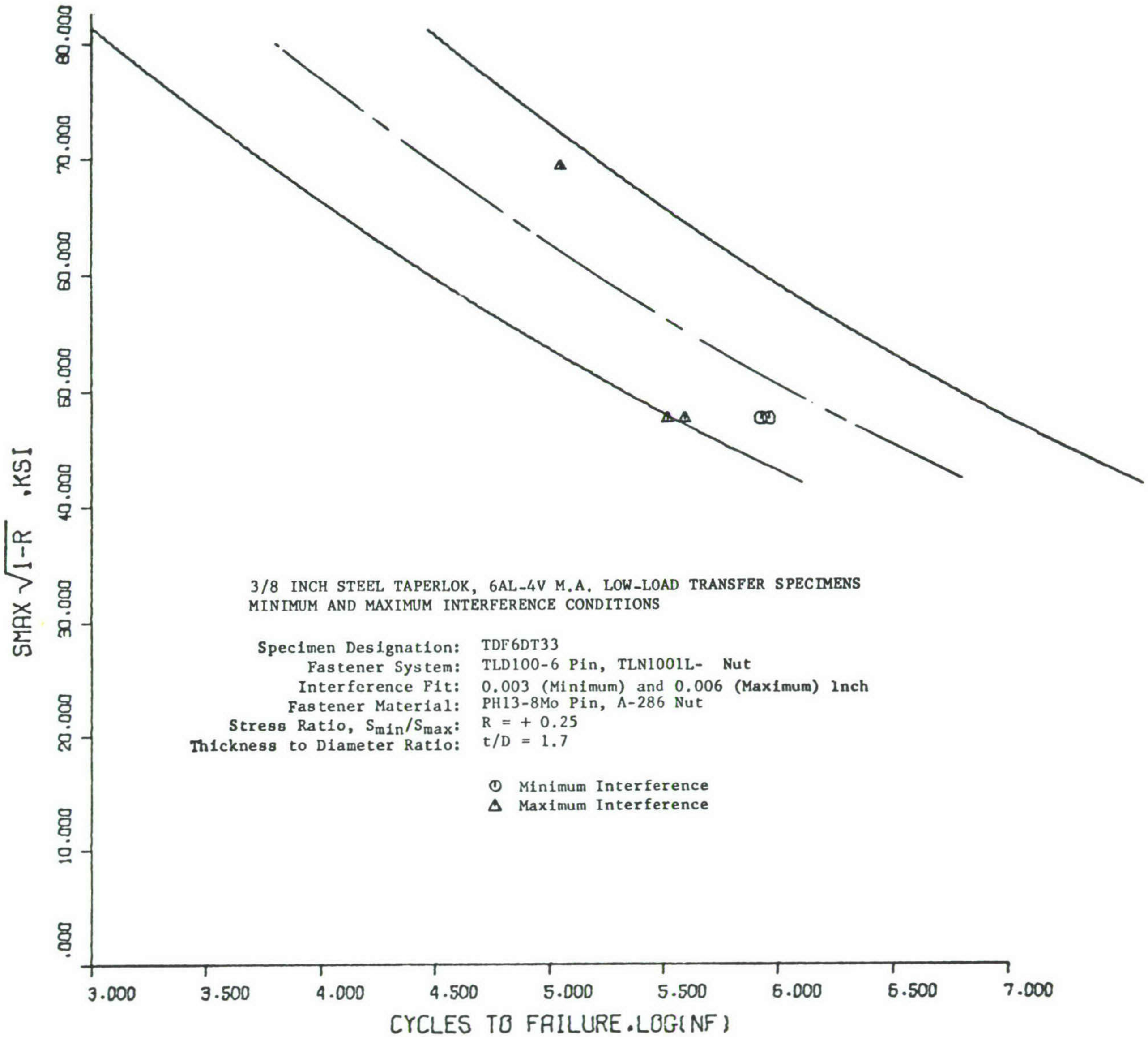



FIGURE C-19. FASTENER FATIGUE IMPROVEMENT DATA

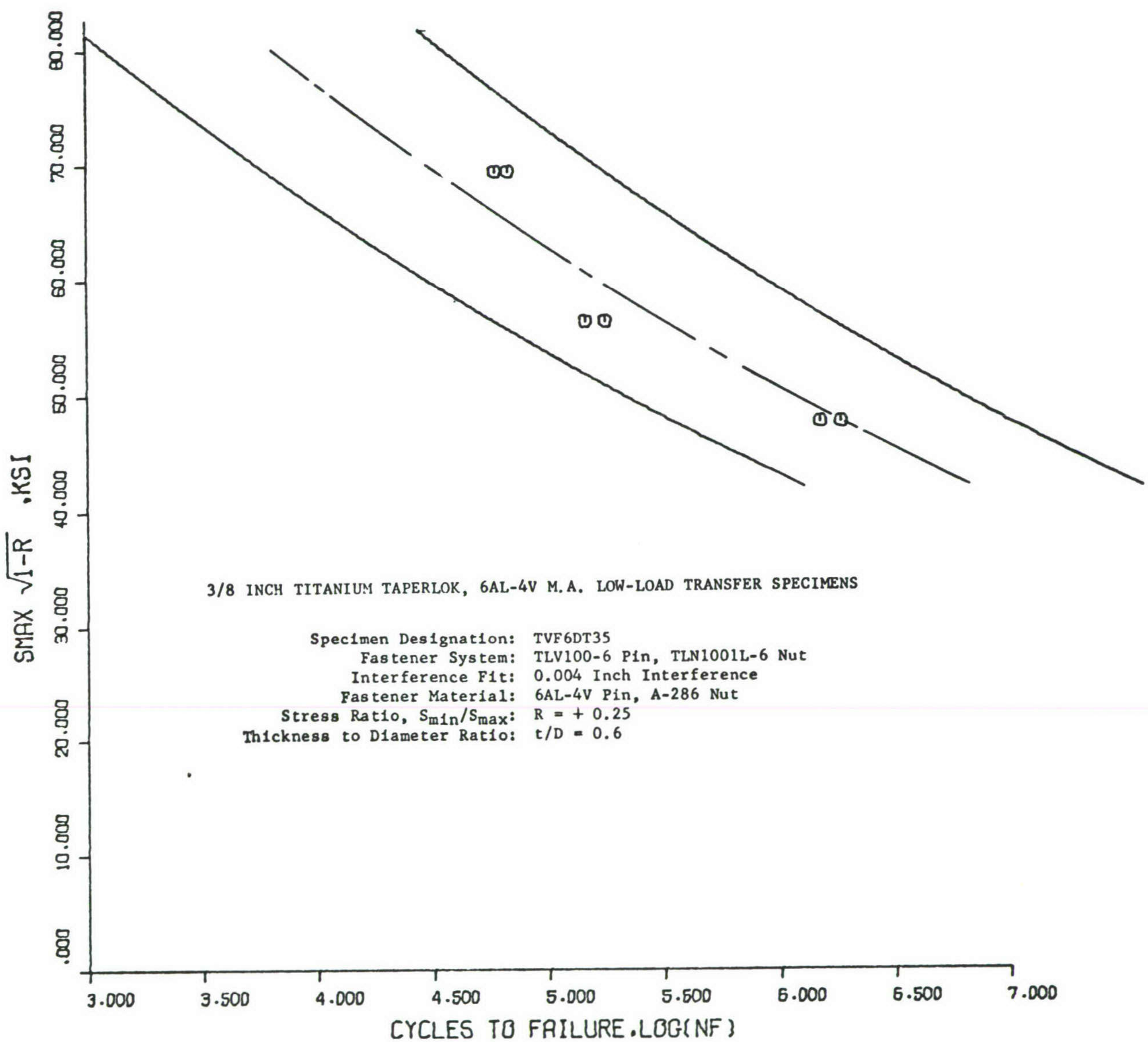



FIGURE C-20. FASTENER FATIGUE IMPROVEMENT DATA

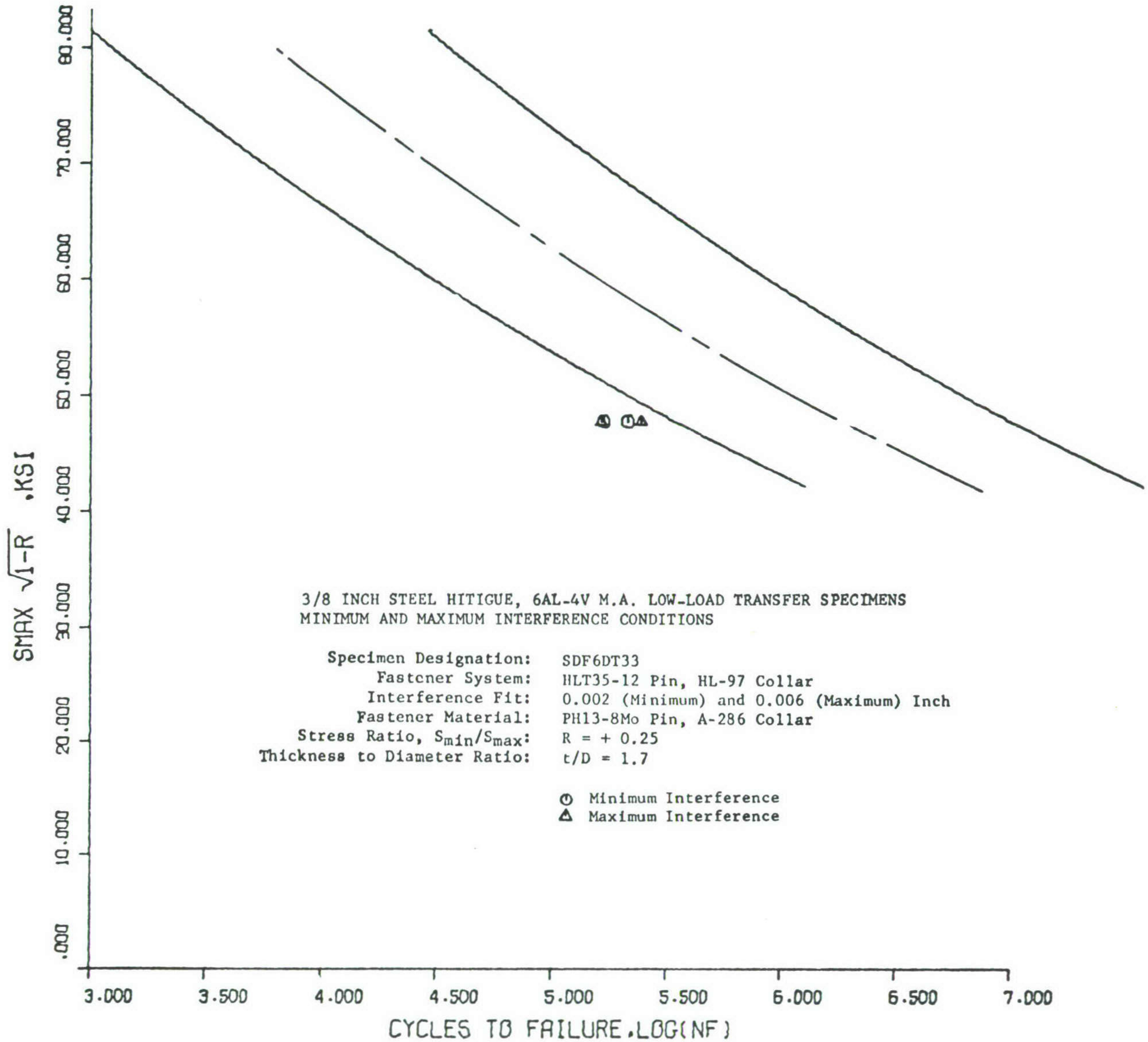



FIGURE C-21. FASTENER FATIGUE IMPROVEMENT DATA

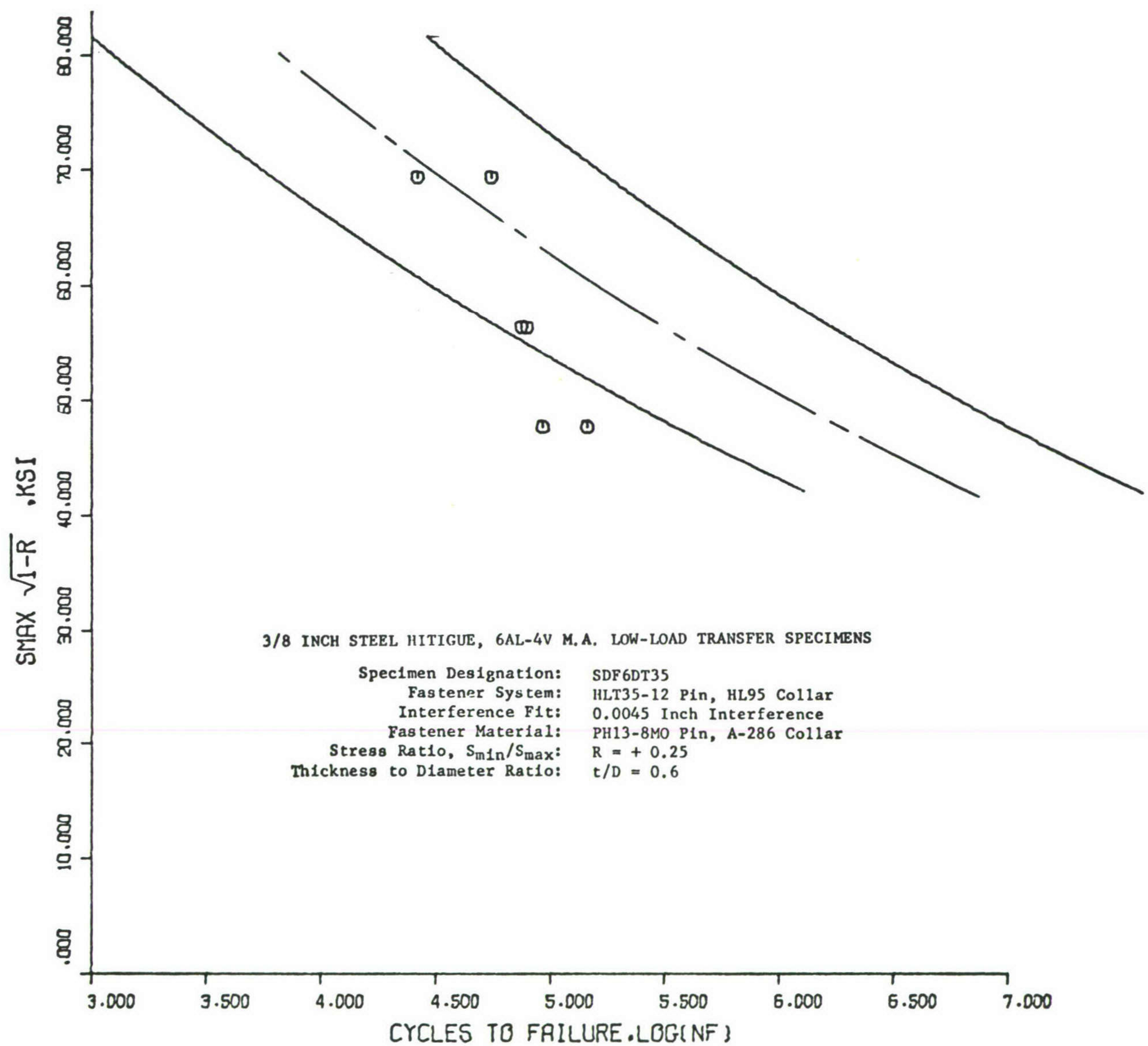



FIGURE C-22. FASTENER FATIGUE IMPROVEMENT DATA

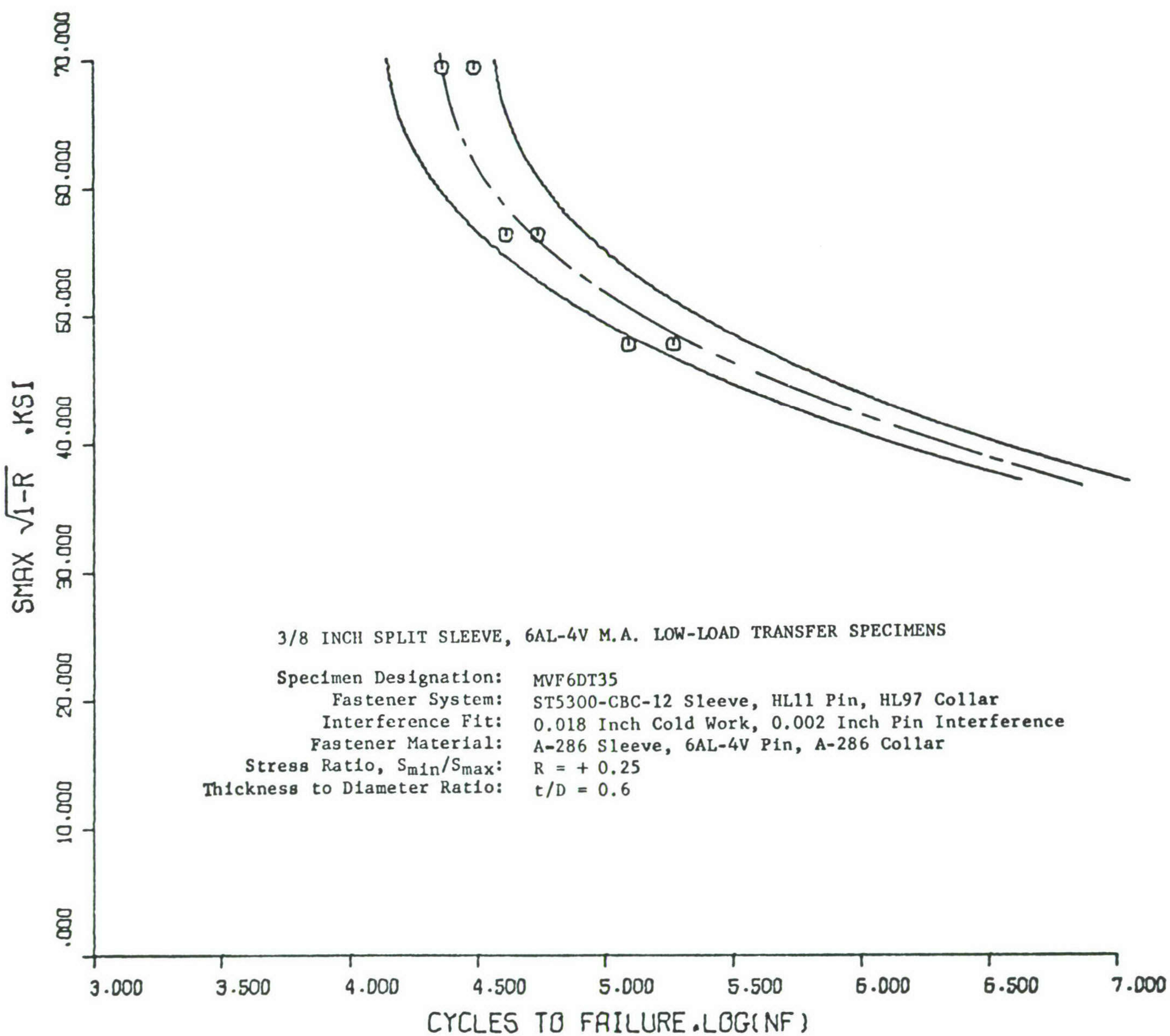



FIGURE C-23. FASTENER FATIGUE IMPROVEMENT DATA

# APPENDIX D

## STATIC-JOINT STRENGTH RESULTS

TABLE D-1. STATIC JOINT STRENGTH OF LOW-LOAD TRANSFER SPECIMENS

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb[a] | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode[b] |
|---|---|---|---|---|---|---|---|
| TDF6DA1-2 | 1.274 | 2.250 | 149,000 | 165,000 | 51,980 | 57,561 | A |
| TDF6DA1-1 | 1.278 | 2.251 | 161,000 | 178,500 | 55,965 | 62,049 | A |
| MDF6DA1-2 | 1.271 | 2.249 | 151,000 | 165,200 | 52,825 | 57,793 | A |
| MDF6DA1-1 | 1.264 | 2.252 | 145,000 | 164,500 | 50,939 | 57,790 | A |
| SDF6DA1-1 | 1.270 | 2.252 | 153,000 | 166,500 | 53,496 | 58,216 | A |
| SDF6DA4-9 | 1.301 | 2.251 | 162,000 | 176,000 | 55,317 | 60,098 | A |
| TVF6DA21-2 | 1.292 | 2.250 | 160,000 | 177,300 | 55,040 | 60,990 | A |
| TVF6DA21-1 | 1.298 | 2.250 | 155,000 | 176,300 | 53,073 | 60,366 | C |
| MVF6DA21-2 | 1.280 | 2.252 | 162,000 | 178,000 | 56,200 | 61,750 | C |
| MVF6DA21-1 | 1.247 | 2.251 | 151,000 | 170,200 | 53,794 | 60,634 | A |
| SVF6DA21-2 | 1.262 | 2.252 | 147,000 | 163,400 | 51,724 | 57,494 | B |
| SVF6DA21-1 | 1.273 | 2.254 | 188,500 | 175,800 | 55,239 | 61,268 | A |
| TDP6DA42-2 | 1.298 | 2.251 | 166,000 | 180,700 | 56,814 | 61,845 | A |
| TDP6DA42-1 | 1.272 | 2.251 | 150,500 | 166,700 | 52,562 | 58,220 | A |
| MDP6DA42-2 | 1.281 | 2.251 | 162,000 | 180,800 | 56,181 | 62,700 | A |
| MVP6DA42-1 | 1.277 | 2.255 | 163,000 | 180,400 | 56,604 | 62,647 | C |
| SDP6DA42-2 | 1.270 | 2.244 | 163,000 | 174,000 | 57,195 | 61,055 | B |
| SDP6DA42-1 | 1.267 | 2.247 | 157,500 | 172,100 | 55,322 | 60,450 | B |
| TDF6DA5-13 | .384 | 2.262 | 48,000 | 52,300 | 55,260 | 60,211 | C |
| TDF6DA5-14 | .389 | 2.269 | 48,600 | 52,900 | 55,062 | 59,933 | A |
| SDF6DA5-9 | .385 | 2.260 | 48,600 | 52,700 | 55,856 | 60,568 | A |
| SDF6DA5-3 | .387 | 2.259 | 48,000 | 52,350 | 54,905 | 59,881 | B |
| MDF6DA5-14 | .389 | 2.266 | 49,800 | 53,700 | 56,496 | 60,921 | A |
| MDF6DA5-10 | .386 | 2.256 | 48,200 | 52,650 | 55,350 | 60,460 | A |
| TVF6DA24-1 | .386 | 2.253 | 48,600 | 52,000 | 55,884 | 59,794 | C |
| TVF6DA24-2 | .386 | 2.256 | 47,600 | 51,450 | 54,661 | 59,083 | B |
| SDF6DA24-1A | .383 | 2.256 | 47,700 | 51,900 | 55,205 | 60,066 | A |
| SDF6DA24-2A | .383 | 2.259 | 47,800 | 52,200 | 55,248 | 60,333 | A |
| MVF6DA24-1 | .384 | 2.260 | 47,800 | 52,300 | 55,079 | 60,265 | B |
| MVF6DA24-2 | .384 | 2.260 | 47,000 | 51,900 | 54,157 | 59,804 | A |

TABLE D-1. (Continued)

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb[(a)] | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode[(b)] |
|---|---|---|---|---|---|---|---|
| TDP6DA44-1A | .384 | 2.263 | 48,600 | 52,450 | 55,927 | 60,357 | A |
| TDP6DA44-2A | .391 | 2.261 | 50,600 | 54,250 | 57,237 | 61,365 | A |
| SDP6DA44-1A | .383 | 2.256 | 48,400 | 52,550 | 56,015 | 60,818 | A |
| SDP6DA44-2A | .383 | 2.252 | 48,000 | 52,300 | 56,681 | 60,637 | B |
| MDP6DA44-1 | .38 | 2.252 | 48,000 | 52,700 | 55,797 | 61,260 | A |
| MDP6DA44-2 | .380 | 2.251 | 47,700 | 51,600 | 55,765 | 60,324 | B |
| TVF6DT30-1 | 1.307 | 2.260 | -- | 357,000 | -- | 120,860 | A |

(a) Yield criteria: 0.2% of gage length (.002 x 4.0 = .008 inch).
(b) Failure Mode: A = bottom sheet through No. 1 hole, top sheet through No. 2 hole; B = both sheets through No. 1 hole, C = both sheets through No. 2 hole.

TABLE D-2. STATIC JOINT STRENGTH OF HIGH-LOAD TRANSFER SPECIMENS

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb(a) | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode(b) |
|---|---|---|---|---|---|---|---|
| TDF6MA8-1 | 1.222 | 3.005 | 46,500 | 61,400 | 25,326 | 33,441 | A |
| TDF6MA8-2 | 1.217 | 3.005 | 43,900 | 61,400 | 24,008 | 33,579 | A |
| SDF6MA8-1 | 1.215 | 3.006 | 43,400 | 61,000 | 23,766 | 33,404 | A |
| SDF6MA8-2 | 1.223 | 3.006 | 45,800 | 61,700 | 24,916 | 33,566 | A |
| MDF6MA8-1 | 1.225 | 3.008 | 38,600 | 62,900 | 20,951 | 34,140 | A |
| MDF6MA8-2 | 1.226 | 3.007 | 35,200 | 61,000 | 19,096 | 33,093 | A |
| TVF6MA26-1 | 1.219 | 3.005 | 46,000 | 54,000 | 25,115 | 29,483 | A |
| TVF6MA26-2 | 1.224 | 3.003 | 47,700 | 55,200 | 25,954 | 30,035 | A |
| SVF6MA26-1 | 1.226 | 3.005 | 39,800 | 54,800 | 21,606 | 29,749 | A |
| SVF6MA26-2 | 1.223 | 3.003 | 43,000 | 55,850 | 23,416 | 30,414 | A |
| MVF6MA26-1 | 1.230 | 3.008 | 44,200 | 55,700 | 23,893 | 30,109 | A |
| MVF6MA26-2 | 1.228 | 3.008 | 40,700 | 54,950 | 22,037 | 29,752 | A |
| TDP6MA46-1 | 1.226 | 3.005 | 46,300 | 68,600 | 25,135 | 37,241 | A |
| TDP6MA46-2 | 1.214 | 3.006 | 46,800 | 69,500 | 25,649 | 38,090 | A |
| SDP6MA46-1 | 1.217 | 3.002 | 45,100 | 67,700 | 24,689 | 37,061 | A |
| SDP6MA46-2 | 1.217 | 3.014 | 48,700 | 67,000 | 26,553 | 36,532 | A |
| MDP6MA46-1 | 1.227 | 3.004 | 49,000 | 68,250 | 26,588 | 37,033 | B |
| MDP6MA46-2 | 1.230 | 3.006 | 46,000 | 68,800 | 24,882 | 37,216 | B |
| TDF6MA13-1 | .385 | 3.004 | 26,800 | 30,150 | 46,345 | 52,138 | C |
| TDF6MA13-2 | .382 | 3.005 | 26,200 | 30,500 | 45,648 | 53,140 | C |
| SDF6MA13-1 | .381 | 2.995 | 26,100 | 30,700 | 45,746 | 53,808 | C |
| SDF6MA13-2 | .381 | 3.005 | 26,900 | 30,850 | 46,990 | 53,419 | C |
| MDF6MA13-1 | .382 | 3.003 | 24,600 | 30,800 | 42,889 | 53,698 | C |
| MDF6MA13-2 | .383 | 3.008 | 26,200 | 30,900 | 45,484 | 53,643 | C |
| TVF6MA28-1 | .382 | 3.005 | 25,900 | 30,100 | 45,125 | 52,443 | D |
| TVF6MA28-2 | .382 | 3.002 | 26,700 | 30,150 | 46,566 | 52,582 | C |
| SVF6MA28-1 | .379 | 3.007 | 26,000 | 29,950 | 45,628 | 52,560 | C |
| SVF6MA28-2 | .378 | 3.006 | 24,900 | 30,300 | 43,828 | 53,332 | C |
| MVF6MA28-1 | .382 | 3.007 | 27,200 | 30,300 | 47,359 | 52,756 | D |
| MVF6MA28-2 | .381 | 3.008 | 27,300 | 30,400 | 47,642 | 53,052 | D |

TABLE D-2. (Continued)

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb[a] | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode[b] |
|---|---|---|---|---|---|---|---|
| TDF6MT38-1 | .463 | 3.003 | 55,000 | 62,600 | 79,115 | 90,047 | E |
| TDF6MT38-2 | .462 | 3.007 | 56,000 | 64,400 | 80,620 | 92,713 | C |
| SDF6MT38-1 | .439 | 2.955 | 59,600 | 64,700 | 91,887 | 99,750 | C |
| SDF6MT38-2 | .446 | 2.955 | 59,400 | 66,300 | 90,141 | 100,612 | C |
| MDF6MT38-1 | .449 | 2.954 | 58,600 | 63,600 | 88,363 | 95,902 | E |
| MDF6MT38-2 | .450 | 2.975 | 60,000 | 63,400 | 89,636 | 94,715 | E |
| TDF6MT36-1 | 1.308 | 2.972 | 65,200 | 69,200 | 33,544 | 35,602 | B |
| TDF6MT36-2 | 1.292 | 2.982 | 65,400 | 69,000 | 33,950 | 35,819 | B |
| SDF6MT36-1 | 1.306 | 2.975 | 60,200 | 62,000 | 30.988 | 31,915 | B |
| SDF6MT36-2 | 1.302 | 2.970 | 58,700 | 62,000 | 30,360 | 32,067 | B |

(a) Yield criteria: 0.04D offset.

(b) Failure Mode: A = Fastener head failure, B = Fastener shank shear-tensile failure, C = Sheet failure threadside, D = Fastener thread failure, E = Fastener shear.

TABLE D-3. STATIC JOINT STRENGTH OF ALUMINUM MEDIUM-LOAD TRANSFER SPECIMENS

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode(a) |
|---|---|---|---|---|---|---|---|
| TDF6LA15-1 | .612 | 1.506 | (b) | 52,200 | 75,415 | 56,636 | ST |
| TDF6LA15-2 | .613 | 1.506 | (b) | 52,100 | 75,147 | 56,435 | ST |
| SDF6LA15-1 | .610 | 1.505 | (b) | 51,700 | 75,004 | 56,315 | ST |
| SDF6LA15-2 | .614 | 1.504 | (b) | 54,700 | 78,909 | 59,234 | ST |
| MDF6LA15-1 | .612 | 1.501 | (b) | 53,900 | 78,217 | 58,675 | ST |
| MDF6LA15-2 | .613 | 1.507 | (b) | 51,750 | 74,577 | 56,019 | ST |

(a) ST = sheet tensile.
(b) Yield loads were not determined due to specimen slippage in grips causing erratic readings.

TABLE D-4. STATIC JOINT STRENGTH OF ALUMINUM 3/16-INCH DIAMETER FASTENED SPECIMENS

| Specimen Identification | Thickness, inches | Width, inches | Yield Load, lb | Ultimate Load, lb | Yield Stress (Gross Area), psi | Ultimate Stress (Gross Area), psi | Failure Mode[a] |
|---|---|---|---|---|---|---|---|
| TDF3MA11-5 | .256 | 1.503 | 11,100[b] | 14,800 | 28,217 | 37,623 | A |
| TDF3MA11-6 | .256 | 1.497 | -- | 14,725 | -- | 38,423 | A |
| SDF3MA11-1 | .258 | 1.503 | -- | 14,300 | -- | 36,806 | A |
| SDF3MA11-2 | .257 | 1.504 | -- | 14,250 | -- | 36,795 | A |
| MDF3MA11-1 | .258 | 1.503 | -- | 14,000 | -- | 36,104 | A |
| MDF3MA11-2 | .258 | 1.500 | 8,700[b] | 14,125 | 22,481 | 36,499 | A |
| TDF3DA6-4 | .519 | 1.120 | 31,080[c] | 35,150 | 53,468 | 60,470 | B |
| TDF3DA6-6 | .519 | 1.123 | 29,400[c] | 35,100 | 50,443 | 60,223 | B |
| SDF3DA6-3 | .518 | 1.123 | 29,700[c] | 35,650 | 51,056 | 61,284 | B |
| SDF3DA6-5 | .519 | 1.124 | 31,500[c] | 35,700 | 53,998 | 61,198 | B |
| MDF3DA6-2 | .520 | 1.124 | 30,600[c] | 35,900 | 52,354 | 61,422 | B |
| MDF3DA6-3 | .521 | 1.118 | -- | 35,850 | -- | 61,547 | B |

(a) Failure Mode: A = fastener head failure, B = bottom sheet through No. 1 hole, top sheet through No. 2 hole.

(b) Yield load determined at 0.04D offset.

(c) Yield load determined at offset = 0.2 percent of 2-inch-gage length.

## APPENDIX E

### SHEET MATERIAL PROPERTIES

TABLE E-1. SHEET MATERIAL FATIGUE PROPERTIES, NO-HOLE SPECIMENS, 7075-T73, T7351 ALUMINUM (R = 0)

| Specimen Identification | Max. Stress Gross Area, ksi | Cycles to Failure | Remarks |
|---|---|---|---|
| | t = 0.250 Inch | | |
| NOSA54-1 | 40.0 | 137,000 | |
| -3 | 50.0 | 26,800 | |
| -4 | 45.0 | 69,900 | |
| -5 | 30.0 | 5,344,700 | |
| -6 | 35.0 | 230,300 | Grip failure |
| -7 | 35.0 | 268,300 | " " |
| | t = 0.190 Inch | | |
| NOSA55-6 | 40.0 | 82,100 | |
| -5 | 37.5 | 102,300 | |
| -3 | 35.0 | 208,000 | |
| -8 | 32.5 | 339,600 | |
| -1 | 32.5 | 152,000 | |
| -9 | 27.5 | 5,000,000 | Did not fail |
| | t = 0.675 Inch | | |
| NOSA56-3 | 37.5 | 73,180 | |
| -7 | 35.0 | 100,300 | |
| -4 | 35.0 | 56,950 | Grip failure |
| -2 | 32.5 | 104,290 | |
| -5 | 30.0 | 114,710 | |
| -6 | 30.0 | 117,240 | |
| -1 | 27.5 | 3,828,030 | Grip failure |
| -8 | 25.0 | 5,464,750 | |

TABLE E-2. SHEET MATERIAL FATIGUE PROPERTIES, OPEN-HOLE SPECIMENS, 7075-T73, T7351 ALUMINUM (R = 0)

| Specimen Identification | Max. Stress Gross Area, ksi | Cycles to Failure | Remarks |
|---|---|---|---|
| | t = 0.250 Inch | | |
| N3SA54-11 | 33.33 | 12,300 | |
| -12 | 29.16 | 22,300 | |
| -3 | 25.00 | 37,000 | |
| -9 | 25.00 | 69,200 | |
| -1 | 20.82 | 56,000 | |
| -7 | 20.82 | 185,700 | |
| -6 | 16.67 | 116,500 | |
| | t = 0.190 Inch | | |
| N6SA55-1 | 33.33 | 10,400 | |
| -2 | 25.00 | 27,000 | |
| -3 | 16.67 | 87,700 | |
| -4 | 33.33 | 10,500 | |
| -5 | 20.83 | 68,800 | |
| -6 | 15.83 | 516,100 | |
| -7 | 16.67 | 5,188,700 | Did not fail |
| -8 | 25.00 | 24,700 | |
| -9 | 20.83 | 39,200 | |
| -10 | 18.75 | 56,400 | |
| -11 | 16.67 | 72,500 | |
| | t = 0.625 Inch | | |
| N6SA56-1 | 25.00 | 26,320 | |
| -5 | 16.64 | 2,270,890 | |
| -9 | 16.67 | 1,302,900 | |
| -7 | 16.83 | 5,579,110 | Did not fail |
| -8 | 14.58 | 1,319,650 | |
| -11 | 16.66 | 149,470 | |
| -3 | 18.74 | 97,350 | |
| -4 | 20.80 | 74,370 | |
| -2 | 24.80 | 34,320 | |

TABLE E-3. SHEET MATERIAL FATIGUE PROPERTIES, OPEN-HOLE SPECIMENS, 6AL-4V, MILL ANNEALED (R = 0)

| Specimen Identification | Max. Stress Gross Area, ksi | Cycles to Failure | Remarks |
|---|---|---|---|
| | t = 0.250 Inch | | |
| N6ST57-8 | 25.00 | 294,880 | |
| -3 | 20.84 | 1,181,220 | |
| -1 | 33.34 | 93,110 | |
| -5 | 29.18 | 280,000 | |
| -7 | 20.84 | 5,497,070 | Did not fail |
| -2 | 25.00 | 310,300 | |
| -6 | 37.50 | 47,740 | |
| -10 | 22.92 | 5,392,110 | Did not fail |
| -9 | 29.18 | 141,880 | |
| | t = 0.625 Inch | | |
| N6ST58-1 | 58.33 | 22,530 | |
| -2 | 41.68 | 78,400 | |
| -9 | 33.32 | 134,250 | |
| -10 | 33.35 | 467,270 | |
| -6 | 29.17 | 292,860 | |
| -4 | 29.16 | 306,170 | |
| -8 | 25.01 | 340,710 | |
| -3 | 24.99 | 517,600 | |
| -7 | 17.62 | 6,481,810 | Did not fail |
| -12 | 20.84 | 5,596,030 | Did not fail |

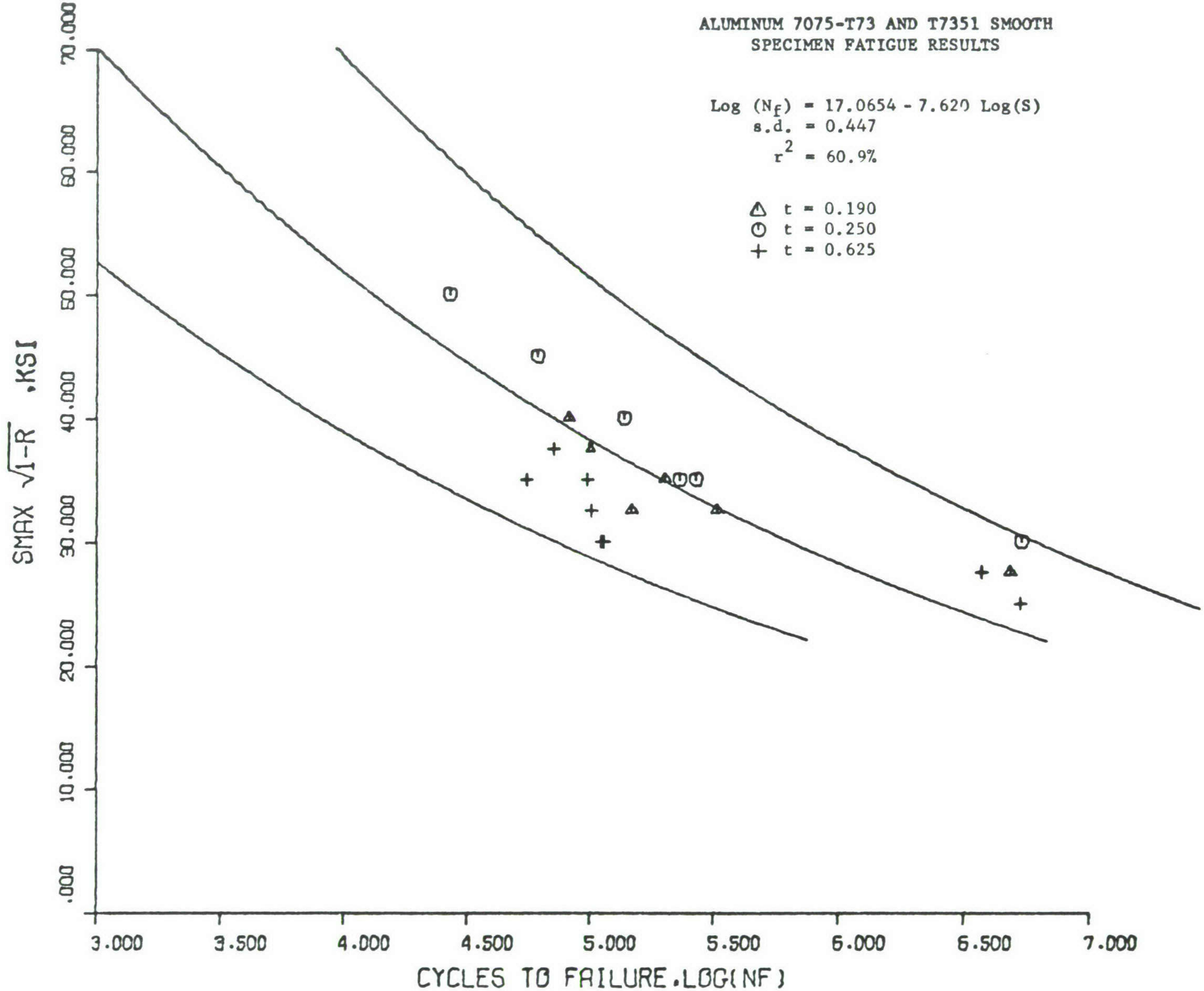



FIGURE E-1. SHEET MATERIAL DATA

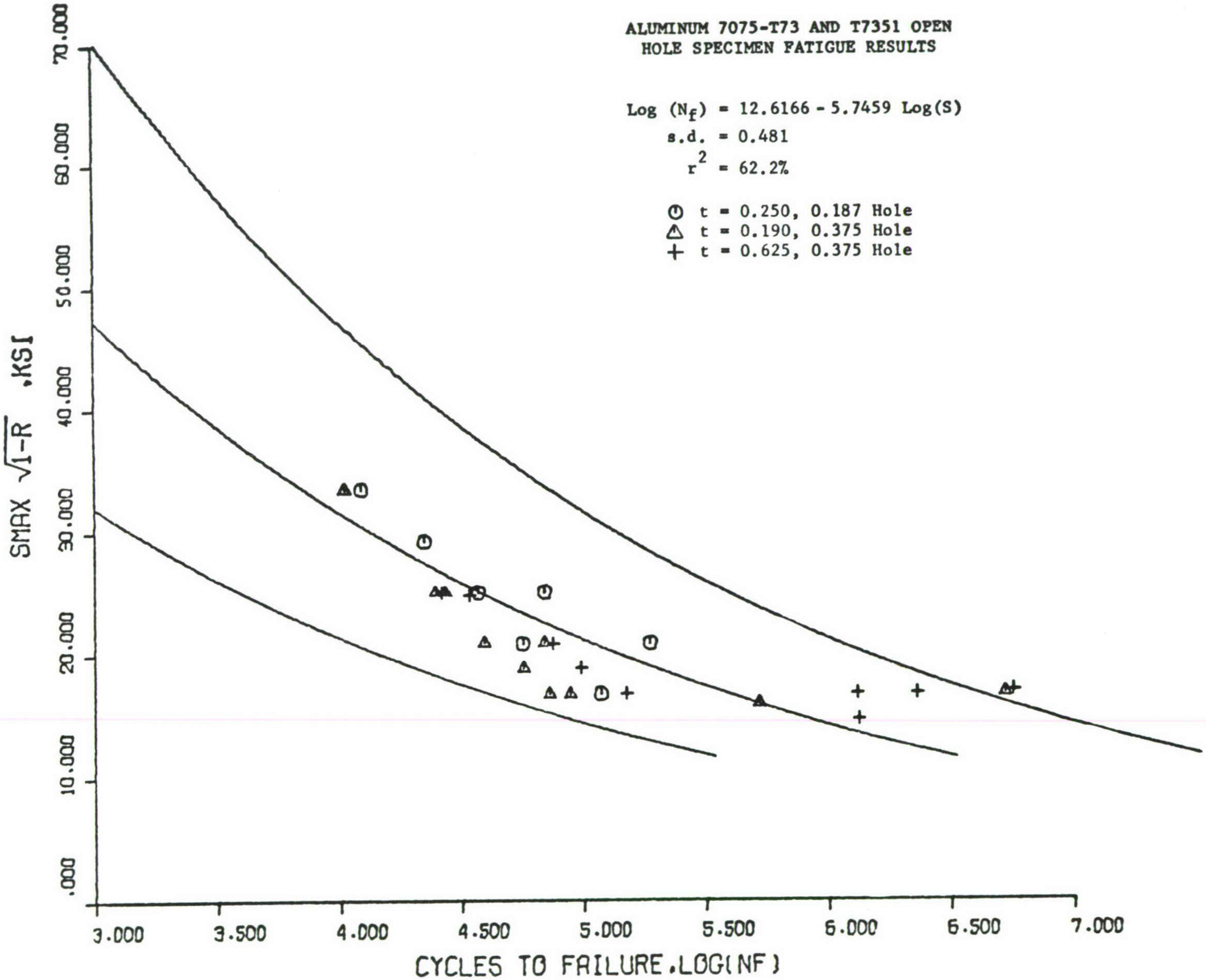



FIGURE E-2. SHEET MATERIAL DATA

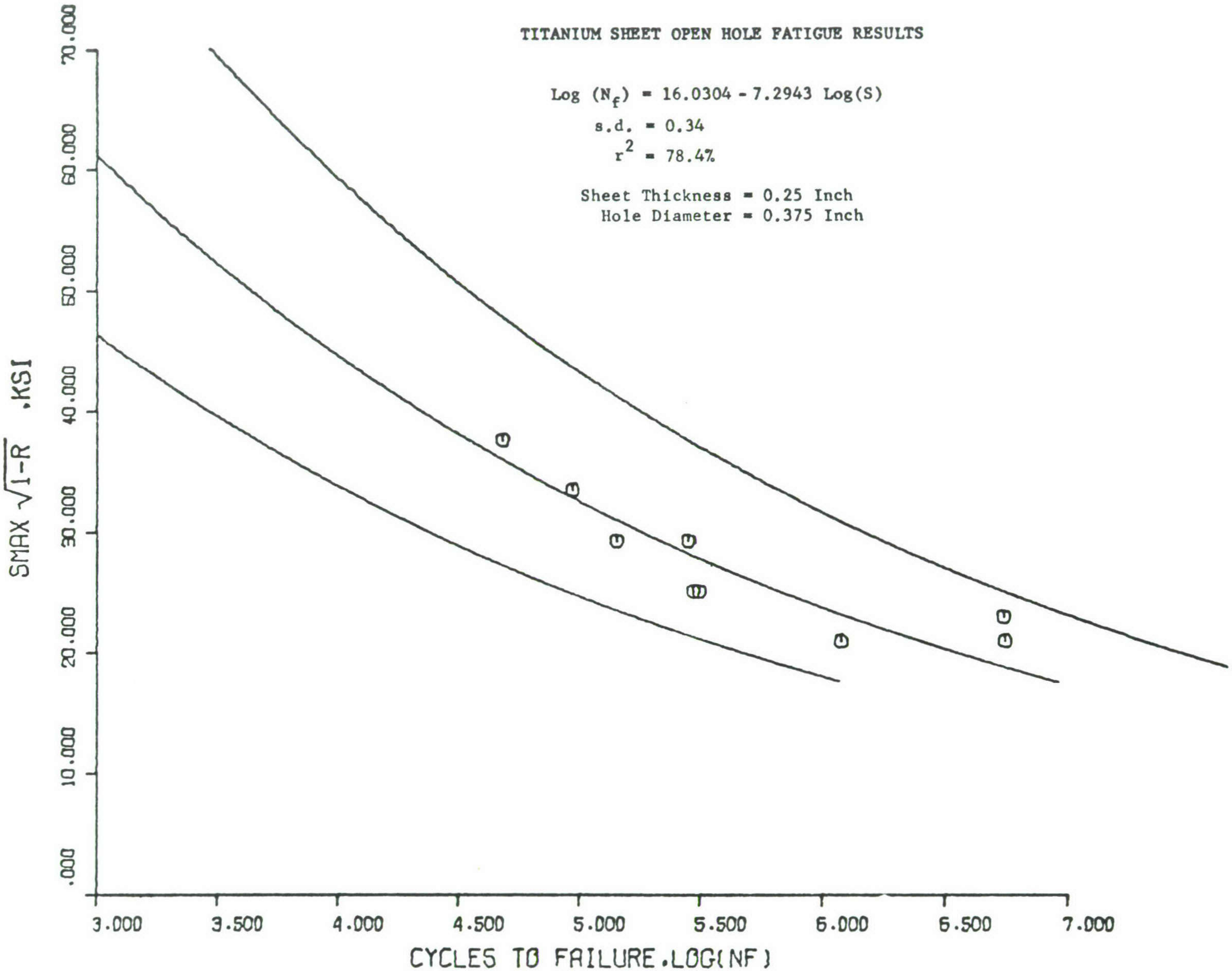



FIGURE E-3. SHEET MATERIAL DATA

# MATERIAL CERTIFICATIONS

PROPERTIES

MM 61-3 D

Pleasanton, California
Aluminum Division Research
Fabrication & Application Research
Mechanical Metallurgy Section



Type of Test: FLAT TENSILE
Spec. Dwg.: 138
Strain Rate to 1% Strain: .005 "/"/Min.
Strain Rate After 1% Strain: ___ "/"/Min.
CHS: .2 "/Min.
Load Rate to Fracture: ___ PSI/Min.
Test Environment: Room
Soak Time: ___ Temp.: 77.

Machine: [illegible]
Scale: [illegible] Range: ___
Extensometer: C-21-14 No.: ___
Strain Scale: 1" = [illegible]
PreAmp. Set: [illegible] Magnification: [illegible]
Gears: Out ___ Hi ___
Pacing Gears: Out 1X Hi ___ Low 8X
Chart Offset for Yield Strength (Inches): [illegible]

Alloy & Temper: 7075-T73
Product Form: Sheet
Lot No.: —
Other Info.: —
W.O. No.: 6399 Project No.: 03993
No. of Spec.: 6
Orig. Branch: —
Originator: BARKER
T. R. No.: 1980 Date: 8-21-73

Remarks: ___

| Specimen No. | Test Temp. °F | Grain Direction | Original Dimensions Inches | Original Area Sq. In. | Ultimate Strength Lbs. | Ultimate Strength PSI | Yield Strength Lbs. | Yield Strength PSI | Elongation in ___ Inches: In. | Elongation %  | Red. of Area % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 72 | TRANS | .4982x.1885 | .09398 | 6770 | 72000 | 5820 | 61900 | .20 | 10.0 | |
| T2 | \| | \| | .5034x.1895 | .09539 | 6950 | 72900 | 6040 | 63300 | [illegible] | 10.5 | |
| T3 | \| | \| | .4970x.1885 | .09374 | 6770 | 72200 | 5860 | 62500 | .20 | 10.0 | |
| T4 | \| | \| | .5015x.1901 | .09552 | 6980 | 73100 | 6110 | 64000 | [illegible] | 10.0 | |
| T5 | \| | \| | .5011x.1894 | .09490 | 6900 | 72700 | 6010 | 63300 | .20 | 10.0 | |
| T6 | \| | \| | .5005x.1901 | .09514 | 6950 | 73100 | 6010 | 63000 | .20 | 10.0 | |
| | | | | | | 72700 | | 63100 | | 10.1 | |
| | | | | | min | 67.0 | | 56.0 | | 8 | |

RECEIVED
5 1973
MFG. TECHNOLOGY

Conductivity 39.2

ORIGINATOR — WHITE
ALLOY FILE — PINK
[illegible] — [illegible]

Tested by: [illegible] Test Date: 9/5/73
Checked by: [illegible] Date: [illegible]

## TEST REPORT

PAGE OF

RMI TITANIUM

RMI Company - NILES, OHIO

| DATE | MILL ORDER NO | GRADE | PACKING LIST NO |
|---|---|---|---|
| June 12, 1973 | 17430X | 6Al-4V | 76874 |

| CUSTOMER NAME | CUSTOMER ORDER NO. |
|---|---|
| Battelle Memorial Institute | |

MATERIAL: H.R. Annealed & Cleaned Ti Sheet

SPECIFICATION: Mil-T-9046F Type 3 Comp C Cond. A (.15 max. O2)

| IDENTIFICATION & REFER | INGOT NO. | LOT | S-R | INGOT NO. | LOT | S-R | INGOT NO. | LOT | S-R | INGOT NO. | LOT | S-R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL NUMBER | 600134 | 03 | 00 | | | | | | | | | |
| TRAVEL CARD NO | 53375 | | | | | | | | | | | |

CHEMISTRY (X) INGOT (AVERAGE OF TOP-CENTER-BOTTOM) ( ) FINAL PRODUCT

| | | | | | |
|---|---|---|---|---|---|
| | C % | .02 | | | |
| | N | .012 | | | |
| | Fe | .17 | | | |
| | Al | 6.3 | | | |
| | V | 3.9 | | | |
| | Cr | | | | |
| | Sn | | | | |
| | Mn | | | | |
| | Mo | | | | |
| | O | .136 | | | |
| FINAL PRODUCT | O | | | | |
| | H (PPM) | 68 | | | |

PROPERTIES

| | | | | | |
|---|---|---|---|---|---|
| ULTIMATE KSI | L | 144.5/146.6 | | | |
| | T | 144.3/145.9 | | | |
| YIELD KSI | L | 138.2/140.5 | | | |
| (0.2%) OFFSET | T | 137.0/139.9 | | | |
| % ELONGATION | L | 10.0/12.0 | | | |
| (INCHES) | T | 11.0/12.0 | | | |
| % REDUCTION | L | | | | |
| IN AREA | T | | | | |
| BEND 105° | L | 5.0 TR | | | |
| | T | 5.0 TR | | | |
| HARDNESS | | | | | |
| STATIC NOTCH | | | | | |
| IMPACT | | | | | |
| ULTRASONIC | | | | | |
| BETA TRANSUS | | | | | |
| TEST FORGE PROCEDURE | | Prod Ann 1450°F 15 min. A.C. | | | |

OTHER DATA

SHIPPED

| | | | | |
|---|---|---|---|---|
| NO. OF PIECES | 2 | | | |
| WEIGHT | 94.0# | | | |
| SIZE | .125 x 30 x 71 | | | |
| TEST PIECES | | | | |

FORM NO. 44 REV. 5/71

THIS IS TO CERTIFY THAT THE ABOVE TEST RESULTS ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY.

SIGNED Ronald Kowalchik

## TEST REPORT

PAGE 1 OF 1

RMI TITANIUM

RMI Company - NILES, OHIO

AUG 22

| DATE | MILL ORDER NO | GRADE | PACKING LIST NO |
|---|---|---|---|
| August 13, 1973 | 17433 | 6Al-4V | 78444 |

| CUSTOMER NAME | CUSTOMER ORDER NO. |
|---|---|
| Battelle Memorial Inst. | G 7650 |

MATERIAL: H.R. Ann & Cld Ti Plate

SPECIFICATION: Mil-T-9046F Type 3 Comp C Cond A

| IDENTIFICATION & REFER | INGOT NO | LOT | S-R | INGOT NO | LOT | S-R | INGOT NO | LOT | S-R | INGOT NO | LOT | S-R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL NUMBER | 890777 | 03 | 00 | | | | | | | | | |
| TRAVEL CARD NO | 32818 | | | | | | | | | | | |

CHEMISTRY X INGOT (AVERAGE OF TOP-CENTER-BOTTOM) FINAL PRODUCT

| | | | | | |
|---|---|---|---|---|---|
| | C % | .01 | | | |
| | N | .017 | | | |
| | • | .18 | | | |
| | Al | 6.5 | | | |
| | V | 3.9 | | | |
| | Cr | | | | |
| | Sn | | | | |
| | Mn | | | | |
| | Mo | | | | |
| | O | .130 | | | |
| FINAL PRODUCT | O | | | | |
| | H (PPM) | 78 | | | |

PROPERTIES

| | | 1 | 2 | 3 | |
|---|---|---|---|---|---|
| ULTIMATE KSI | L | 145.6 | 139.8 | 142.1 | |
| | T | 157.5 | 152.8 | 158.2 | |
| YIELD KSI (0.2%) OFFSET | L | 132.1 | 127.7 | 132.1 | |
| | T | 150.9 | 130.2 | 151.5 | |
| % ELONGATION (INCHES) | L | 10.0 | 11.0 | 10.0 | |
| | T | 11.0 | 13.0 | 11.0 | |
| % REDUCTION IN AREA | L | | | | |
| | T | | | | |
| BEND 105° | L | | | | |
| | T | | | | |
| HARDNESS | | | | | |
| STATIC NOTCH | | | | | |
| IMPACT | | | | | |
| ULTRASONIC | | | | | |
| BETA TRANSUS | | | | | |
| TEST FORGE PROCEDURE | | | | | |
| | | Prod Anneal 1450°F 15 min. A.C. | | | |

OTHER DATA

SHIPPED

| | | | | |
|---|---|---|---|---|
| NO. OF PIECES | 3 | | | |
| WEIGHT | 379.4 | | | |
| SIZE | .190 x 36 x 96 | | | |
| TEST PIECES | | | | |

FORM NO. 44 REV. 5/71

THIS IS TO CERTIFY THAT THE ABOVE TEST RESULTS ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY

SIGNED Ronald Kovalchuk

## TEST REPORT



RMI TITANIUM

**RMI Company** - NILES, OHIO

| DATE | MILL ORDER NO | GRADE | PACKING LIST NO |
|---|---|---|---|
| August 13, 1973 | 17431 | 6Al-4V | 78444 |

| CUSTOMER NAME | CUSTOMER ORDER NO. |
|---|---|
| Battelle Memorial Inst. | G 7650 |

MATERIAL: H.R. Ann & Cld Ti Plate

SPECIFICATION: Mil-T-9046F Type 3 Comp C Cond. A

| IDENTIFICATION & REFER | INGOT NO. | LOT \| S-R | INGOT NO. | LOT \| S-R | INGOT NO | LOT \| S-R | INGOT NO | LOT \| S-R |
|---|---|---|---|---|---|---|---|---|
| MATERIAL NUMBER | 890777 | 04 00 | | | | | | |
| TRAVEL CARD NO | 32811 | | | | | | | |

CHEMISTRY X INGOT (AVERAGE OF TOP-CENTER-BOTTOM) ☐ FINAL PRODUCT

| | | | | |
|---|---|---|---|---|
| C % | .01 | | | |
| N | .017 | | | |
| Fe | .18 | | | |
| Al | 6.5 | | | |
| V | 3.9 | | | |
| Cr | | | | |
| Sn | | | | |
| Mn | | | | |
| Mo | | | | |
| O | .130 | | | |
| FINAL PRODUCT O | | | | |
| FINAL PRODUCT H (PPM) | 1 116 2 105 | | | |

PROPERTIES

| | | 1 | 2 | | |
|---|---|---|---|---|---|
| ULTIMATE KSI | L | 144.1 | 144.3 | | |
| | T | 154.3 | 154.4 | | |
| YIELD KSI (0.2%) OFFSET | L | 134.2 | 133.6 | | |
| | T | 147.5 | 146.7 | | |
| % ELONGATION (INCHES) | L | 11.0 | 10.0 | | |
| | T | 12.0 | 12.0 | | |
| % REDUCTION IN AREA | L | | | | |
| | T | | | | |
| BEND 105° | L | | | | |
| | T | | | | |
| HARDNESS | | | | | |
| STATIC NOTCH | | | | | |
| IMPACT | | | | | |
| ULTRASONIC | | | | | |
| BETA TRANSUS | | | | | |
| TEST FORGE PROCEDURE | | | | | |
| | | Prod Anneal 1450°F | 15 min. A.C. | | |

OTHER DATA

SHIPPED

| | | | | |
|---|---|---|---|---|
| NO. OF PIECES | 2 | | | |
| WEIGHT | 236.2# | | | |
| SIZE | .250 x 36 x 72 | | | |
| TEST PIECES | | | | |

FORM NO. 44 REV. 5/71

THIS IS TO CERTIFY THAT THE ABOVE TEST RESULTS ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY.

SIGNED Ronald Kovalchik

## TEST REPORT

Page 1 of 1

RMI TITANIUM

RMI Company - NILES, OHIO

| DATE | MILL ORDER NO | GRADE | PACKING LIST NO |
|---|---|---|---|
| August 8, 1973 | 17434 | 6Al-4V | 78527 |

| CUSTOMER NAME | CUSTOMER ORDER NO. |
|---|---|
| Battelle Memorial Institute | C 7650 |

MATERIAL: H.R. Annealed & Cleaned Ti Plate

SPECIFICATION: Mil-T-9046F Type 3 Comp C Cond A

| IDENTIFICATION & REFER | INGOT NO | LOT | S-R | INGOT NO. | LOT | S-R | INGOT NO | LOT | S-R | INGOT NO | LOT | S-R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL NUMBER | 890777 | 06 | 00 | | | | | | | | | |
| TRAVEL CARD NO | 32817 | | | | | | | | | | | |

CHEMISTRY X INGOT (AVERAGE OF TOP-CENTER-BOTTOM) ☐ FINAL PRODUCT

| | | | | |
|---|---|---|---|---|
| C % | .01 | | | |
| N | .017 | | | |
| Fe | .18 | | | |
| Al | 6.5 | | | |
| V | 3.9 | | | |
| Cr | | | | |
| Sn | | | | |
| Mn | | | | |
| Mo | | | | |
| O | .130 | | | |
| FINAL PRODUCT O | | | | |
| FINAL PRODUCT H (PPM) | 60 | | | |

PROPERTIES

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| ULTIMATE KSI | L | 141.1 | 141.5 | | |
| | T | 146.1 | 146.5 | 147.4 | 146.7 |
| YIELD KSI | L | 128.2 | 128.6 | | |
| (0.2%) OFFSET | T | 133.6 | 135.1 | 137.0 | 135.0 |
| % ELONGATION | L | 13.0 | 13.0 | | |
| (INCHES) | T | 13.0 | 13.0 | 15.0 | 15.0 |
| % REDUCTION | L | | | | |
| IN AREA | T | | | | |
| BEND 105° | L | | | | |
| | T | | | | |
| HARDNESS | | | | | |
| STATIC NOTCH | | | | | |
| IMPACT | | | | | |
| ULTRASONIC | | | | | |
| BETA TRANSUS | | | | | |
| TEST FORGE | | | | | |
| PROCEDURE | | | | | |
| | | Production Annealed 1450°F 15 minutes Air Cool. | | | |

OTHER DATA

SHIPPED

| | | | | |
|---|---|---|---|---|
| NO. OF PIECES | 7 | | | |
| WEIGHT | 2533.0# | | | |
| SIZE | .625 X 36 X 96 | | | |
| TEST PIECES | | | | |

FORM NO. 44 REV. 5/71

THIS IS TO CERTIFY THAT THE ABOVE TEST RESULTS ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY.

SIGNED Ronald Kowalczyk

APPENDIX F

## ANALYSIS OF THE HIGH-LOAD-TRANSFER JOINT

Proposed MIL-STD-1312 Test 21 (Shear Joint Fatigue-Constant Amplitude) requires the use of bending restraints on high-load-transfer joints. The proposed test suggests two types of restraints--the flexure pivot/90-degree-offset and the sandwich type. The purpose of these restraints is to minimize the bending stresses from the joint and, hence, produce consistent joint failures originating near the fasteners.

Urzi* has shown that relatively thin ($t/D \sim 0.5$) unrestrained joints may be subjected to combined bending and tensile stresses at the fay surface as much as 2.64 times greater than the nominal (P/A) tensile stress. He has also shown that the addition of restraints in the fastened area can reduce the maximum stress to as little as 1.18 times the nominal stress.

It was the intent of this phase of the program to conduct high-load-transfer joint tests in a three-post 50-kip-capacity fatigue-test system. The majority of these joints were to be relatively thick ($t/D \sim 1.5$). It was believed that the sandwich-type restraint would be most practical because of the geometry of the system. When load was applied to the first specimen, it became apparent that although bending might have been reduced in the joint area, bending loads had been transferred to the load train. This observation was manifest in the form of extreme deflections (± 0.010 inch) of the hydraulic actuator when measured at the actuator-test frame platen location. Experience has shown that deflections at that location exceeding ± 0.003 inch will severely reduce actuator seal life. As a result, it was decided to attempt to stabilize the sandwich-type restraint by providing lateral support in the form of rollers (see Figure F-1). It was envisioned that the rollers could be adjusted laterally to reduce joint deflections while providing negligible friction loading.

Test Series 9 and 10 were conducted for the TaperLok and HiTigue fastener systems and although considerable time was expended adjusting the

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* Urzi, R. B., "Standardization of Fatigue Tests of Installed Fastener Systems", Lockheed-California Company Report LR25280, Naval Air Development Center Contract N62269-71-C-0450 (July, 1972).

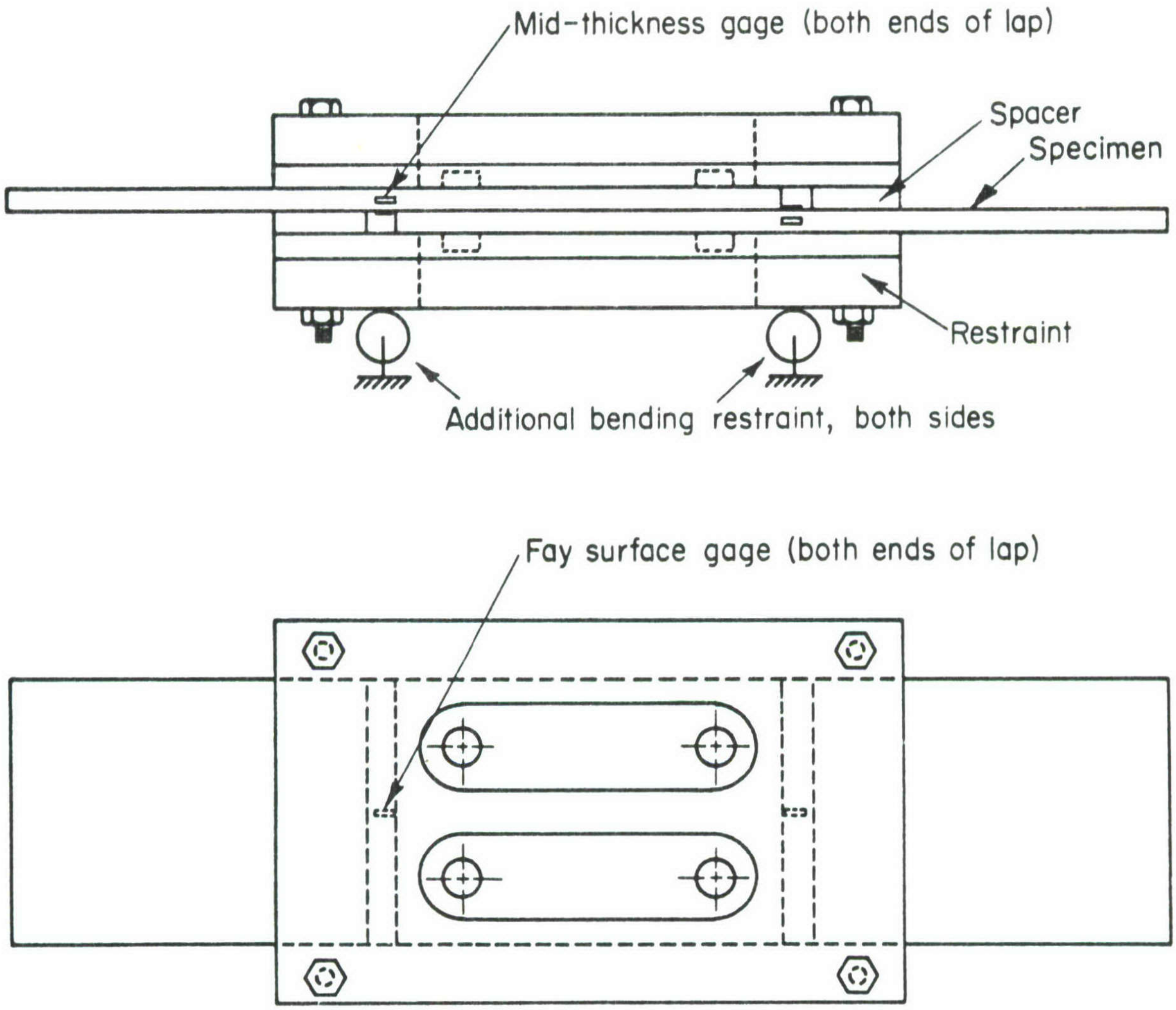


FIGURE F-1. BENDING RESTRAINT SYSTEM AND STRAIN GAGE LOCATIONS

rollers for each specimen, actuator deflections were reduced to a level no greater than ± 0.0015 inch during cyclic loading. When Test Series 9 and 10 were completed and the data analyzed, a definite trend was observed. It was apparent that specimens subjected to high cyclic loads tended to fail at the fay surface at or near the fastener holes while low cyclic loads generally produced failures in the gross section near the edge of the lap. Considerable concern was expressed that these differing failure modes would cloud the analysis of fastener effects upon joint life and it was suspected that the restraint system was not adequately removing bending stresses.

A small experimental program was devised whereby electric strain gage versus applied load data could be obtained to evaluate the effectiveness of the restraint system. Strain gages with measuring elements 1/16 inch in length were applied to a high-load-transfer specimen as shown in Figure F-1. Applied load and measured strain data were obtained at loading increments up to 20 kips for the three test conditions of no restraint, sandwich restraint, and sandwich and roller restraint. The data for similar gage locations was averaged and is presented in regression curve-fitted form in Figure F-2. The analysis of Figure F-2 is discussed in the following paragraphs.

## No Restraint

These data are very encouraging in that a linear relationship exists between the midthickness (tension only) gages and the fay surface (tension and bending) gages. In addition, the latter data show that the strains due to combined tension and bending are 2.58 times greater than those for tension only which compares well with the 2.64 relationship found by Urzi for similar conditions.

## Sandwich Restraint

Data obtained with the sandwich restraint installed on the specimen provides some interesting observations. First, the strains at the fay surface are noted to be linear but greater in magnitude (approximately 6 percent) than the unrestrained case. Although part of the difference may be attributed to normal experimental errors, it is believed that the majority of the increase

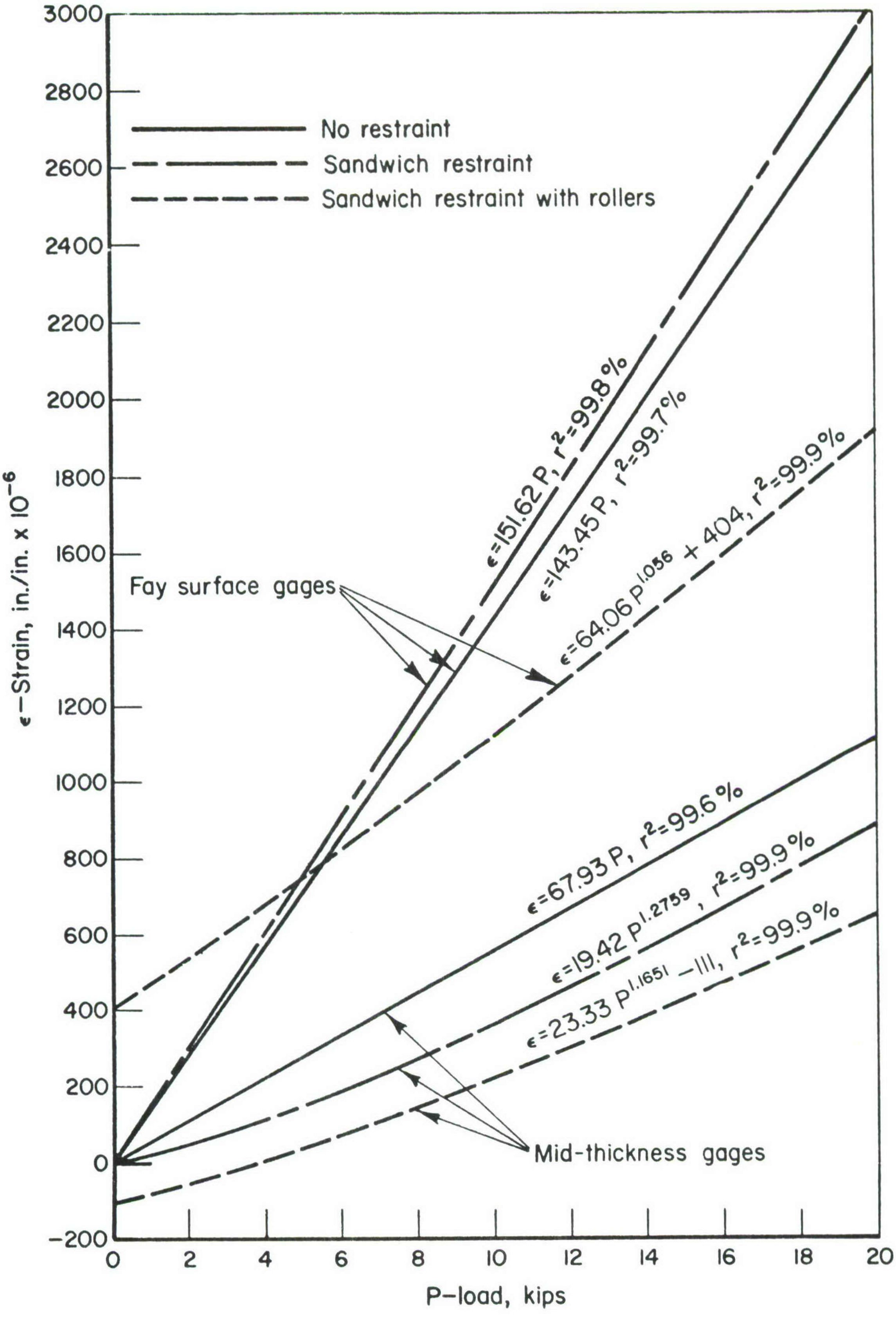


FIGURE F-2. STRAIN GAGE RESULTS FOR HIGH-LOAD-TRANSFER JOINT

is attributable to the fact that the fay surface strain gages were placed in a small open area between the spacer plate and the joint end. It is possible that high lateral compressive loads could be applied to the joint surface near the gages (by the restraint) through the spacer. As a result, additional positive Poisson strains would be reflected in the load-strain data.

The second area of interest lies in the analysis of data taken at midthickness. It is apparent that strain data obtained at loads up to 10 kips are not linear. This indicates that some load is being transferred through the sandwich restraint instead of through the joint. In fact, the similarity in slope of the no-restraint and sandwich-restraint curves at high loads supports such a hypothesis. If the higher load portion of the curve is used to project a linearized curve, it is found that the projection intersects the fay-surface curve at a total strain magnitude nearly equivalent to that of the no-restraint curve when both are evaluated at the same load (say 20 kips).

## Sandwich and Roller Restraint

As noted earlier, the rollers were added to reduce lateral motion of the joint and hydraulic actuator. This was accomplished by making lateral adjustments of the rollers at various load levels until the maximum lateral movement at all loads was less than ± 0.002 inch. The final curves presented in Figure F-2 indicate the effect of the rollers on the strain state of the high-load-transfer joint.

It is apparent from the fay-surface curve that the adjustment of the rollers for minimum deflection imposes a bending moment or preload upon the joint at zero load. Bending in the joint has been substantially reduced as the strain excursion for the fay-surface curve is approximately 1500 $\mu\varepsilon$ for the 20 kip load range as compared to approximately 1100 $\mu\varepsilon$ for the unrestrained midthickness curve for the same range. However, the reduction in bending is completely overshadowed by the nonlinearity of the midthickness curve for this condition and the apparent bypass of approximately 30 percent of the applied load through the restraint system. This latter fact is evidenced by the approximate 750 $\mu\varepsilon$ excursion of the sandwich and roller

restraint curve for a 20 kip load application as compared to an approximate 1100 $\mu\varepsilon$ excursion for the no-restraint curve for the same load application.

## Conclusions and Recommendations

As a result of the above analysis, it was determined that the restraint systems proposed for use in MIL-STD-1312, Test 21, will not adequately control bending in thick-joint specimens. Apparently, if bending is reduced measurably via a restraint system, considerable load is bypassed around the fastened area by the restraints. In addition, it is apparent that even the sandwich-type restraint bypasses some load around the joint, even at relatively low loads. Hence, two additional unknowns must enter the fatigue analysis of the single-lap high-load-transfer joint--the amount of bending in the joint and the amount of load transferred through the restraint system--both functions of applied load. Both of these variables make it nearly impossible to access the effect of a given fastener system on the present high-load-transfer joint geometry. As a result, it is recommended that consideration be given to the development of a new high-load-transfer joint geometry which is either sufficiently symmetrical or adequately restrainable such that fastener effects on joint fatigue life can be assessed independent of joint thickness.

APPENDIX G

DATA ANALYSIS AND PLOTTING COMPUTER PROGRAM

```
BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL BCL

                   PROGRAM FASFAT(INPUT,OUTPUT,PLOT,TAPE5=INPUT,TAPE99=OUTPUT)
000003             DIMENSION SPEC(7),NUM(50),HT(2),SMX(50),R(50),TK(50),NRR(50),NF(50
                  1),X(51),Y(50),Z(51),W(50),AT(3,3),LT(9),B(3),YR(50),BS(3),S(3),SEQ
                  2(50),IND(15)
                  3,Z1(51),Z2(51)    ,SALT(51),SMAXR(51)
000003             REAL NRR,NF,M
000003             INTEGER CURV
000003             EXTERNAL FUNC
000003             COMMON Y,YR,W
000003        2    FORMAT(A3,2X,A3,2X,A3)
000003        4    FORMAT(A3,8X,6A1,A2,3A10,A9,2F5.0,2F6.0)
000003     6       FORMAT(A10,5F10.0)
000003        8    FORMAT(10X,A8,3X,F6.1,5X,F6.2,5X,F10.0)
000003       10    FORMAT(8X,6A1,A2)
000003       12    FORMAT(////10X,I3,* DATA POINTS ANALYZED ON CURVE *,I2/20X,*STANDA
                  1RD DEVIATION= *,F6.3/20X,*R-SQUARED STAT.= *,F6.1//11X,*LOG(NF)= *
                  2,F9.4,2X,F7.4,* X (SEQ)*////20X,*EQUIVALENT STRESS*,5X,*FATIGUE LI
                  3FE*/)
000003       13    FORMAT(10X,F15.6)
000003       14    FORMAT(A10)
000003       16    FORMAT(1H1)
000003       18    FORMAT(10X,F20.1,3X,1PE20.3)
000003             READ 2,RCOMP,STRESS,LIMIT
000015       96    CURV=0
000016             III=0
000017       98    CURV=CURV+1
000021             I=1
000022             J=1
000023             II=1
000024             PRINT 16
000027             READ 240,FACTOR
000035      240    FORMAT(F10.0)
000035      102    READ 4,TOD,(SPEC(K),K=1,7),ALLOY,FORM,HT,TYS,TUS,SIZE,WIDTH
000067             IF(EOF,5)120,105
000072      105    PRINT 10,(SPEC(K),K=1,7)
000104      108     READ 6, NUM(I),NF(I),SMX(I),SALT(I),SMAXR(I),R(I)
000124             IF(EOF,5)115,110
000127      110    IF(SMX(I).LE.0.0)GO TO 102
```

```
000131          PRINT 8,NUM(I),SMX(I),R(I),NF(I)
000145          I=I+1
000147          GO TO 108
000147    115   IND(J)=I-II
000152          J=J+1
000153          II=I
000154          GO TO 102
000154    120   N=I-1
000156          J=J-1
000157          M=0.50
000161          AVG=0.
000162          DO 130  I=1,N
000163          SEQ(I)=(SMX(I)*(1-R(I))**0.5)
000173          X(I)=SEQ(I)
000174          AVG=AVG+X(I)
000176          Y(I)=ALOG10(NF(I))
000202    130   W(I)=1.0


000206          AVG=AVG/N
000210          CALL REG1(1,3,FUNC,N,W,Y,X,1,AT,LT,B,YR,SSD,BS,S,IE)
000230          CALL RSQR(SSD,N,SD,TSS,RS)
000234          PRINT 12,N,CURV,SD,RS,B(1),B(2)
000254          PRINT 13,B(3)
000262          NN=41
000263           START=AVG
000265          Z(1)=3.
000266          ICOUNT =0.
000267          DO 210  I=1,41
000270    220   VALUE=-Z(I)+B(1)+B(2)*START+B(3)*ALOG10(START)
000301          DVAL=B(2)+B(3)/START
000303          AGAIN =START-VALUE/DVAL
000306          ABF=ABS(START-AGAIN      )
000310          IF(ABF.LT.0.05)GO TO 209
000312          START=AGAIN
000313          ICOUNT=ICOUNT+1
000314          IF(ICOUNT.GT.50)GO TO 175
000317          GO TO 220
000317    209      X(I)=AGAIN
000321          Z1(I)=Z(I)+FACTOR* SD
000325          Z2(I)=Z(I)-FACTOR* SD
000327          ZZ=10.0**Z(I)
```

```
000333    135   PRINT 18,X(I),ZZ
000343          Z(I+1)=Z(I)+0.1
000346          ICOUNT=0
000347    210   CONTINUE
000351          IF(CURV.GT.1)GO TO 140
000354          CALL QIKSET(8.0,3.0,0.5,7.0,0.0,10.0)
000360          CALL QIKPLT(Z,X,NN,27H*CYCLES TO FAILURE,LOG(NF)*,23H*EQUIVALENT S
               1TRESS,KSI*,35H*FASTENER FATIGUE IMPROVEMENT DATA*)
000364          CALL PLOT(-9.0,1.0,-3)
000367          CALL QLINE(Z1,X,NN,1)
000372          CALL QLINE(Z2,X,NN,1)
000375          GO TO 145
000376    140   CALL QLINE(Z,X,NN,1)
000401    145   I2=0
000402          I3=III
000404          DO 155 K=1,J
000405          III=I3+K
000407          I1=IND(K)
000410          I2=I2+I1
000412          DO 150 I=1,I1
000413          Y(I)=Y(I2-I1+I)
000417    150   SEQ(I)=SEQ(I2-I1+I)
000424    155   CALL QLINE(Y,SEQ,-I1,III)
000433          READ 14,CHECK
000440          IF(EOF,5)165,160
000443    160   BACKSPACE 5
000445          GO TO 98
000446    165   READ 14,CHECK
000454          IF(EOF,5)175,170
000457    170   BACKSPACE 5
000461          CALL PLOT(9.0,0.0,-3)
000464          GO TO 96
000465    175   CALL PLOT(9.0,0.0,-3)



000470          CALL ENDPLT
000471          CALL EXIT
000472          END
```

```
FASFAT

PROGRAM LENGTH INCLUDING I/O BUFFERS
005372

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
2       -  000505   4       -  000510   6       -  000515   8       -  000520
10      -  000525   12      -  000530   13      -  000555   14      -  000560
16      -  000562   18      -  000564   96      -  000015   98      -  000017
102     -  001035   105     -  000072   108     -  000104   110     -  000127
115     -  000147   120     -  000154   135     -  000333   140     -  000376
145     -  000401   160     -  000443   165     -  000446   170     -  000457
175     -  000465   209     -  000317   220     -  000270   240     -  000572

BLOCK NAMES AND LENGTHS
        -  000226

VARIABLE ASSIGNMENTS
ABF     -  002216   AGAIN   -  002215   ALLOY   -  002173   AT      -  001507
AVG     -  002202   B       -  001531   BS      -  001534   CHECK   -  002223
CURV    -  002160   DVAL    -  002214   FACTOR  -  002170   FORM    -  002174
HT      -  000745   I       -  002165   ICOUNT  -  002212   IE      -  002204
II      -  002167   III     -  002164   IND     -  001624   I1      -  002222
I2      -  002220   I3      -  002221   J       -  002166   K       -  002172
LIMIT   -  002163   LT      -  001520   M       -  002157   N       -  002201
NF      -  001257   NN      -  002210   NRR     -  001175   NUM     -  000663
R       -  001031   RCOMP   -  002161   RS      -  002207   S       -  001537
SALT    -  002011   SD      -  002205   SEQ     -  001542   SIZE    -  002177
SMAXR   -  002074   SMX     -  000747   SPEC    -  000654   SSD     -  002203
START   -  002211   STRESS  -  002162   TK      -  001113   TOD     -  002171
TSS     -  002206   TUS     -  002176   TYS     -  002175   VALUE   -  002213
W       -  000144C01 WIDTH  -  002200   X       -  001341   Y       -  000000C01
YR      -  000062C01 Z      -  001424   ZZ      -  002217   Z1      -  001643
Z2      -  001726

START OF CONSTANTS
000474

START OF TEMPORARIES
000632

START OF INDIRECTS
000643
```

```
                SUBROUTINE FUNC(NX,X,NF,F)
000007          DIMENSION X(NX),F(NF)
000007          F(1)=1.0
000010          F(2)=X(1)
000011          F(3)=ALOG10(X(1))
000017          RETURN
000020          END
```

```
                SUBROUTINE RSQR(SSD,N,SD,TSS,R)
          C     THIS SUBROUTINE CALCULATES THE STANDARD DEVIATION AND R-SQUARED
          C     STATISTIC FOR A PARTICULAR SET OF REGRESSED DATA
000010          DIMENSION Y(50),YREG(50),W(50)
000010          COMMON Y,YREG,W
000010          A=N-1
000012          TL=0.0
000012          TID=0.0
000013          SUM=0.0
000015          DO 10  I=1,N
000016          TID=Y(I)**2.0+TID
000023          TL=Y(I)+TL
000025          TERM=(ABS(Y(I)-YREG(I))**2.0)*W(I)
000034     10   SUM=SUM+TERM
000040          SD=SQRT(SUM/A)
000046          TSS=TID-(TL**2.0)/N
000054          R=(1.0-SUM/TSS)*100.0
000057          RETURN
000060          END
```



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